Regenerating Mixed-Oak Historic Woodlots at Gettysburg National Military Park

T. W. Bowersox, D. S. Larrick,
G. L. Storm and W. M. Tzilkowski

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School of Forest Resources
The Pennsylvania State University
University Park, PA 16802

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Executive Summary

Woodlots are significant features of the historic scene at Gettysburg National Military Park. Recent inventories of these historic woodlots indicated a general lack of seedling recruitment in uneven-aged stands with a mature mixed-oak overstory. Seedling-sized stems (≤150 cm in height) of shrub and tree species were abundant, averaging over 40,000 per hectare. Tree species were dominated by ash and cherry, and white-tailed deer had foraged on many seedlings. A management strategy is needed to maintain structure and species composition of the historic woodlots. However, the strategy needs to be based on an understanding of factors controlling the establishment and development of the park woodlots. This report summarizes the results and conclusions of a project that was designed to evaluate the effects of various-sized openings in the canopy, with and without foraging by white-tailed deer, on understory vegetation.

Effects of canopy opening and fencing to exclude white-tailed deer on ground-level vegetation were assessed at Gettysburg National Military Park. Herbaceous plants and woody seedling-sized stems were monitored in three uneven-aged, mixed-oak woodlots. Canopy opening levels on 0.20 ha treatment units were closed (~100% canopy), partially open (50-60% canopy) and completely open (0% canopy). Overstory treatments were conducted in March 1993. Pre-treatment inventories were conducted in 1992, and post-treatment inventories were conducted one-, two- and four-years-after treatment in 1993, 1994 and 1996, respectively. Densities of white-tailed deer in the park during March-April ranged from 0.36 to 0.52 deer per ha (0.15 to 0.21 deer per acre) from 1992 to 1996. Fences to exclude deer were installed on one-half of the understory inventory plots prior to the 1993 growing season. Pre-treatment inventories of the July herbaceous vegetation indicated forbs, grasses, and vines covered an average of 30% of the ground. Total herbaceous coverage increased to a maximum average of 56% of the ground after canopy treatments were conducted. Woodlot, canopy opening, and fencing significantly influenced the coverage of herbaceous vegetation. Over all of the after-canopy-treatment inventories, average total herbaceous coverage was 36% in closed, 55% in partially-open and 72% in completely-open canopy treatments. There was an equal average number of seedling-sized shrub and tree species per 2.0 m^2 plot before treatment (2.3 shrub and 2.4 tree species). Four years after treatment, the average number of seedling-sized shrub species did not change (2.3) but the average number of seedling-sized tree species dropped to 1.4. Woodlot, but not canopy or fence treatment, influenced the number of shrub and tree species.

Inventories of woody vegetation before canopy treatment recorded an average density of 5.6/m^2 shrub and 4.0/m^2 tree seedling-sized stems. Average density of seedling-sized shrub stems increased slightly after the canopy treatments, varying between 6.4/m^2 and 6.8/m^2 for all post-treatment inventories. Average density of seedling-sized tree stems increased to 6.0/m^2 two years after treatment but dropped to 1.7/m^2 four years after treatment. Ash dominated the tree species with an average of 2.0/m^2 pre-treatment seedling-sized stems but dropped to an average of 0.8/m^2 seedling-sized stems four years after treatment. Densities of oak seedling-sized stems averaged between 0.9 and 1.0/m^2 for pre-treatment and two years after canopy treatment, and dropped to 0.2/m^2 four years after treatment. Yellow poplar was not recorded in the pre-treatment inventory but had an average of 1.6/m^2 seedling-sized stems two years after canopy treatment and 0.2/m^2 four years after treatment. Woodlot consistently influenced the average

density of pre- and post-treatment seedling-sized stems. Pre-treatment average densities of shrub and tree (total) seedling-sized stems were 12.3, 6.9 and 9.6 per m^2 for Bushman Hill, Herr Ridge and Powers Hill woodlots, respectively. Average densities of total seedling-sized stems reached a maximum at Herr Ridge in the one year after treatment inventory (7.6/m^2). Maximum average densities of total seedling-sized stems at Bushman Hill (6.5/ m^2) and Powers Hill (15.3/ m^2) occurred in the second growing season after treatment. Average densities of total seedling-sized stems four years after treatment for Bushman Hill, Herr Ridge and Powers Hill declined to 9.3, 5.7 and 9.5/ m^2, respectively. Most temporal density changes among the woodlots were due to changes in tree species densities. The study woodlots were selected to represent the range of conditions resource managers would need to account for when developing a park woodlot management program. Woodlot was frequently a significant variable in the understory responses. We consider this to represent the range of responses to be expected from a park woodlot management program.

Canopy treatment had no effect on the average density of shrub seedling-sized stems but did influence the average density of tree seedling-sized stems. Two years after treatment, closed canopy had the lowest (4.4/m^2), completely open had moderate (6.4/m^2) and partially open had the highest (7.1/m^2) average number of tree seedling-sized stems. Four years after treatment, closed canopy had the highest (2.1/m^2), partially open had moderate (1.9/m^2) and completely open had the lowest (1.2/m^2) average number of tree seedling-sized stems. Canopy treatment had a substantial effect on height structure of shrub and tree seedling-sized stems. At pre-treatment, about 23% of the shrub and 8% of the tree seedling-sized stems were >25 cm tall. Four-years-after canopy treatment, the relative number of shrub seedling-sized stems >25 cm tall increased to 60, 64 and 79% for the closed, partially-open, and completely-open canopy treatments, respectively. Tree seedling-sized stems responded similarly, with the greatest percentage of seedling-sized stems >25 cm tall occurring in the completely-open canopy (91%) four years after canopy treatment. Closed- and partially-open canopy treatments had 36 and 45%, respectively, of the tree seedling-sized stems >25 cm four years after canopy treatment.

Fence treatment had no consistent effect on the average number of seedling-sized shrub or tree species or on the average density of shrub and tree seedling-sized stems. Fence treatment did have an effect on the height structure of the seedling community. In the pre-treatment year and the first year after canopy treatment, the relative number of shrub and tree seedling-sized stems >25 cm were generally <25% and <10%, respectively, regardless of fence treatment. In the fourth year after canopy treatment, nearly 71% of fenced shrub seedling-sized stems and 56% of fenced tree seedling-sized stems were >25 cm tall. Comparatively, 62% of unfenced shrub seedling-sized stems and 43% of unfenced tree seedling-sized stems were >25 cm tall in the fourth year after canopy treatment.

Reducing the foraging by white-tailed deer is essential to increasing the height and vigor of shrub and tree seedling-sized stems. Without reduced foraging by white-tailed deer, the potential for desirable tree species to grow into the sapling-size class will be limited. As compared to no fence treatment, fence treatment in closed canopy increased the four-years-after treatment average density of 51-150 cm height class seedling-sized stems for shrub species from 1.0/m^2 to 1.7/m^2 and for tree species from 0.1/m^2 to 0.4 /m^2. Fence treatment in partially-open canopy resulted in these respective changes over no fence of 1.6/m^2 to 3.5/m^2 for shrub species and $0.2/m^2$ to $0.4/m^2$ for tree species. Fence in completely-open canopy resulted in these changes over no fence treatment of $3.1/m^2$ to $5.1/m^2$ for shrub species and $0.6/m^2$ to $1.1/m^2$ for tree species.

Canopy and fence treatments had little effect on species composition of the existing vegetation. It is particularly important to note that none of the treatments increased the oak component in the woodlots. There can be a number of factors controlling successful establishment and growth of oak in these woodlots by natural processes but canopy level and white-tailed deer density did not appear to be among them.

If park management limits foraging by white-tailed deer and removes non-native plants, we believe a program to renew desirable shrubs and trees can be developed for the park woodlots. In places where there is a lack of sufficient densities of desirable species, we recommend developing practices to stimulate germination and growth of additional woody seedlings without a major expansion of the herbaceous community. Closed and partially-open canopies can be used to establish species like ash, hickory and oak that germinate best in the shelter of an overstory with abundant litter. In places where there are sufficient densities of vigorous seedling-sized shrub and tree stems, partially- and completely-open canopies should be used to enable the seedling-sized stems to grow into the mid- and overstory strata. Completely-open canopy would be needed for shade-intolerant species like black cherry and yellow poplar.

Effects of woodlot, canopy condition, litter condition, and white-tailed deer foraging on abundance and species composition of new shrub and tree germinants (recruitment seedlings) were also evaluated. Within each woodlot-canopy treatment unit, two pairs of fenced and unfenced plots were established. Litter was removed from half of each plot to expose the humus or mineral soil surface. Densities of recruitment seedlings by species were recorded in August of the first, second, and fourth growing seasons after canopy treatments. There were more tree species than shrub species at each inventory; however, by the end of the fourth growing season, shrubs were more abundant than trees in terms of density of seedlings. The four dominant individual species were grape, redbud, ash, and yellow poplar. Numbers of species and densities of seedlings were consistently lowest at Herr Ridge, indicating possible regeneration site limitations at this woodlot regardless of management practices. Numbers of species and densities of seedlings were generally lowest in closed canopy treatment and highest in partially-open canopy treatment. A partially-open canopy with some exposure of mineral soil is recommended to establish the greatest density and diversity of new seedlings. Litter removal is needed to increase numbers of shrub species and density of shrub seedlings, and densities of species requiring a mineral seedbed (grape, redbud, and yellow poplar).

To understand how to restore woodlots to Civil War condition, when oak was the dominant vegetation, the effects of woodlot, canopy treatment, and fencing treatment on the survival and growth of planted northern red oak acorns, seedlings, and saplings were examined. Within each canopy treatment unit in each woodlot, two pairs of fenced and unfenced plots were established. At each pair of plots, 40 acorns, eight two-year-old, bare-root seedlings, and six four-year-old, bare-root saplings were planted. Foraging damage by white-tailed deer and small mammals was monitored during the second and fourth growing seasons after canopy treatment. At the end of the second and fourth growing seasons, survival and height were recorded for each of the three

sources of regeneration. Four-year survival of direct-seeded seedlings and planted seedlings was maximized in fenced plots. Planted sapling four-year survival and height were greatest in partially- or completely- open canopy. To maximize four-year height of direct-seeded seedlings and planted seedlings, the completely-open canopy, fence treatment combination was recommended. If acorns pilferage by small mammals can be reduced, direct seeding would be an excellent practice to add northern red oak to the understory of the mixed-oak woodlots.

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Introduction

Gettysburg National Military Park (GNMP) was established in 1895 to commemorate a Civil War battle fought there in July of 1863. Originally established under the US War Department, GNMP was transferred to the National Park Service in 1933. In 1995, GNMP covered about 1,560 ha, with 643 ha occupied by woodlots. These woodlots range in size from 2 to 24 ha.

Before the battle, the woodlots were important resources for the residents. Historic photographs and documents and recent research reports (Fairweather and Cavanaugh 1990, Storm et al. 1994) suggest a general pattern to the 1863 condition and subsequent development of these woodlots. Open-grown white oak (*Quercus alba* L.) trees were the dominant vegetation in the 1863 woodlots that were being used as pastures. In 1993, there were about 15 residual white oak trees per ha, estimated to be >135 years old. These trees typically had rapidly tapering boles with wide spreading crowns that had large diameter branches originating near the ground. Their diameters at 1.4 m above ground (DBH) generally were >60 cm. A second group of trees became established around 1900 (±25 years) when the under stocked woodlots were retired from being used as pastures. This group was primarily northern red oak (*Quercus rubra* L.), black oak (*Quercus velutina* Lam.), white oak, bitternut hickory (*Carya cordiformis* [Wangenh.] K. Koch.), mockernut hickory (*Carya tomentosa* Nutt.) and shagbark hickory (*Carya ovata* [Mill.] K. Koch). These trees were generally between 30 and 60 cm DBH in 1993, with closed stand architecture of slowly tapering boles with narrow crowns. A third group of trees developed in response to occasional openings in the canopy; these trees were mainly black cherry (*Prunus serotina* Ehrh.), flowering dogwood (*Cornus florida* L.), mazzard cherry (*Prunus avium* L.), white ash (*Fraxinus americana* L.), and hickories. In 1993, the third group of trees was generally between 3 and 30 cm DBH.

Storm et al. (1994) evaluated overstory and understory of six GNMP woodlots. They concluded that the species composition, density and size of the trees >12 cm DBH should be capable of maintaining an acceptable woodlot appearance for at least 25 years. They also concluded there was a variety of tree species present in the seedling and sapling sizes (stems<12 cm DBH). Overall there was an adequate density of seedling-sized stems (average of 23,584 per ha) but the density of saplings (826 per ha) was approximately one-half the density needed to sustain the woodlots after the next 25 years. Furthermore, oak species accounted for 44% of the density of trees in the overstory but only 6% of the sapling-sized stems.

White-tailed deer *(Odocoileus virginianus)* browsing may be influencing height growth and species composition of the understory at GNMP (Bowersox et al. 1993, Tzilkowski et al. 1993). The white-tailed deer population of a 2,862 ha area on and around the park has been monitored since 1987 according to procedures described by Storm et al. (1992). About 26% (749 ha) of the sample area was forested (Storm et al. 1992). The number of deer counted in March-April varied considerably among years but there was an overall increasing trend from 1987 to 1992. March-April mark-resight based estimates increased from 721 in 1987 to 1,441 in 1991, and decreased to 1,148 in 1995 (National Park Service 1996). Density increased from 0.25 deer per hectare of total land (forested and non-forested) in 1987 to 0.38 deer/ha in 1990 through 1995. Herd density was 1.47 deer/ha of forested land from 1990 through 1995. In comparison, the

Pennsylvania Game Commission had an over-winter statewide management goal from 1990 to 1995 of 0.08 and an Adams County goal of 0.09 deer per hectare of forested land (Pennsylvania Game Commission 1997). There were no estimates of white-tailed deer abundance prior to 1987, but park personnel have considered the population to be high for at least 20 years. In the fall of 1995 the park started a management program to maintain 0.10 deer per forested hectare (National Park Service 1996).

Storm et al. (1992) evaluated the availability and use of woody twigs by white-tailed deer in six park woodlots. White ash, mazzard cherry and black cherry were the most abundant twigs within 1.8 m of ground level with 6,868, 13,359 and 11,166 twigs/ha, respectively. All oak species totaled 1,661 twigs/ha. Frequency of browsing on oak species ranged from none for pin oak to 100% for black oak. White ash, mazzard cherry and black cherry had 44, 25 and 24%, respectively, of twigs browsed by white-tailed deer.

Woodlot management practices may also account for the lack of oak seedlings, saplings and small diameter trees. In 1986, six pairs of 10 x 10 m fenced and unfenced plots were established in six park woodlots. Initially, in 1986 there were 5.9 seedling-sized shrub and tree stems, combined, per m^2 in the fenced plots, and 4.0 stems/m^2 in the unfenced plots. After the 1994 growing season, values dropped to 4.7 stems/m^2 in fenced areas and 2.5 stems/m^2 in unfenced areas. Loss of seedling-sized tree species stems between 1986 and 1994 was substantial. The 1986 to 1994 decline of tree species stems was 2.4 to 0.6/m^2 in fenced areas and from 1.8 to 0.3/m^2 in unfenced areas. In contrast, during that same time period, densities of seedling-sized shrub species stems increased from 0.3 to 1.9/m^2 in fenced areas and from 0.1 to 1.1/m^2 in unfenced areas. There was considerable variation among woodlots and the sample size was small. Nevertheless, these data suggest that seedling survival was being influenced by some factor in addition to white-tailed deer. Competition or interference from overstory vegetation is one possible reason for seedling mortality. Openings in the canopy may be needed to establish replacements for stems lost to natural mortality, enhance the vigor of remaining stems, and maintain a healthy, sustainable stand structure.

Maintaining these woodlot areas as tree-dominated communities is important to the park's mission to preserve the historic scene. Resource managers want to manage these woodlots to sustain an uneven-aged structure. These conditions have raised a concern for the future of these woodlots. They were created under frequent partial-cutting practices before 1863 and a change in land use about 1900. There has been no tree cutting activity since 1895. The canopy trees are at or are approaching maturity. The existing woodlots were established at a time when there were no deer. At the time that this study was started, deer density was very high and may have substantially influenced understory vegetation. A research program has been developed to provide a basis for actively managing these woodlots. This project was designed to evaluate the effects of various size openings in the canopy, with and without white-tailed deer, on three understory considerations. They were:

a. Abundance and species composition of naturally established (existing) herbaceous, shrub and tree plants.
b. Abundance and species composition of new shrub and tree germinants (recruitment seedlings) for natural regeneration process, when litter was removed or retained.
c. Survival and growth of planted acorns, seedlings, and saplings.

Procedures

Woodlots and Canopy Treatments

Regeneration potential was evaluated in three mixed-oak woodlots. These woodlots were Bushman Hill (22 ha), Herr Ridge (17 ha), and Powers Hill (21 ha). Locations of three replications of three canopy treatments in each of the woodlots were selected in April 1992. Details of the canopy treatments and the locations of the treatment units within each woodlot were presented in Bowersox et al. (1992). Overall study design, maps of treatment units in the three woodlots, and treatment unit design are given in Appendix B. Felling of the canopy trees was conducted in March 1993. Directional felling was used to uniformly distribute the residue over the 0.20 ha circular plot. Boles and branches were cut to place all material within 1 m of the ground. No material was removed from the treatment units, and minimal disturbance to the soil was permitted when the canopy trees were felled. Canopy treatments to the 0.20 ha areas were:

1. Closed. No changes in the overstory. Average stocking levels based on standards developed for upland central hardwoods by Roach and Gingrich (1968) were 115, 100 and 99% for Bushman Hill, Herr Ridge, and Powers Hill, respectively;
2. Partially-open. Overstory canopies were reduced by single tree felling to achieve a modified structure (Bowersox et al. 1993) with the goal at 50 to 60% of fully stocked level. Average stocking levels after tree felling were 53, 55 and 52% for Bushman Hill, Herr Ridge, and Powers Hill, respectively; and
3. Completely-open. All stems >2 cm DBH were felled.

Existing Herbaceous and Woody Plants

Abundance, composition and structure of understory vegetation were measured before and after canopy treatments were executed. All understory inventory plots were randomly located within the central 450 m^2 of each 0.20 ha treatment unit to minimize the effect of adjacent community and site conditions. Three pairs of fenced and unfenced 2.0 m^2 circular plots were established within each 0.20 ha treatment unit to inventory the naturally established (existing) herbaceous, shrub and tree plants. There were 27 pairs of fenced and unfenced existing regeneration plots per canopy treatment for all study woodlots. Wire fences 1.2 m high to exclude white-tailed deer were randomly assigned and installed in August 1992.

Herbaceous and woody plants were inventoried in 1992 (pre-treatment), 1993 (one-year-after treatment), 1994 (two-years-after treatment) and 1996 (four-years-after treatment). July coverage of forbs, grasses, and vines on each plot was ocularly estimated to the nearest 5%. Total herbaceous coverage was the summation of the three species groups, which, due to layering, overlap, and inclusions, may exceed 100%. Coverage by individual herbaceous species was inventoried on a subset (n=30) of the plots, with half of the plots fenced to exclude white-tailed deer. Height class and density of stems per shrub and tree species ≤150 cm in height (seedlings) were inventoried in August of each measurement year. Seedling height classes were 1-25, 26-50, 51-75, 76-100, 101-125, and 126-150 cm.

Density of existing seedlings per species by the six height classes was calculated for each combination of woodlot, canopy treatment and fencing treatment. Because there were poor distributions of densities of seedlings by species and height class, the data were pooled by shrub, tree and total species groups and by 1-25 and 26-150 height classes.

Analysis of variance was used to test for significant main and appropriate interaction factors on herbaceous coverage, and shrub and tree species occurrence and density values. Mean separations were performed on those parameters which showed significant treatment effects with Tukey's method of multiple comparisons. Significance at $\alpha = 0.05$ was used in all cases.

Recruitment of Shrubs and Trees

Within each canopy treatment unit two pairs of fenced and unfenced 4.0 m^2 circular plots were established (total of 18 pairs per woodlot) to evaluate effects of deer browsing. In May 1993 litter was manually removed from one-half of each plot to expose the humus or mineral soil surface. An attempt was made to tag seedlings to determine timing of germination and survival patterns but marking materials used in the procedure were not durable. Densities of recruitment seedlings by species were recorded for each permutation of woodlot, canopy treatment, fencing treatment, and litter treatment in August of one, two and four-years-after treatments.

Analysis of variance (significance at $\alpha = 0.05$), with Tukey's method of multiple comparisons, was used to determine significant predictors of densities of grape (*Vitis* spp.), redbud (*Cercis canadensis* L.), ash (*Fraxinus* spp.), and yellow poplar (*Liriodendron tulipifera* L.) seedlings. These were the only species with sufficient densities of seedlings well enough distributed to be analyzed separately. Recruitment seedlings were also pooled by shrub, tree, and total species groups for analyses of number of species and densities of seedlings.

Artificial Oak Regeneration

Within each 0.20 ha treatment unit, two pairs of fenced and unfenced 12 m^2 rectangular plots were established, for a total of 18 paired plots per canopy treatment and 54 paired plots for the study. Wire fences 1.2 m high were used to exclude deer, but small mammal movements were unrestricted. Each set of plots was randomly located within the central 450 m^2 of each treatment unit to provide a buffer of at least 11 m between the specific canopy treatment and adjacent untreated conditions.

Acorns were collected from trees growing on The Pennsylvania State University's University Park campus. Bare-root seedlings were 2-0 stock, acquired from the Pennsylvania Bureau of Forestry nursery with unknown seed sources. Saplings were 4-0 stock, acquired from Musser Nurseries, Indiana, Pennsylvania, with unknown seed sources. In May 1993, at each pair of fenced and unfenced plots, 40 acorns, eight bare-root seedlings (about 0.3 m in height), and six bare-root saplings (>1.0 m in height) were planted, resulting in a total of 2,160 acorns, 432 seedlings, and 324 saplings. To prevent pilferage by small mammals, individual acorns were planted in protectors described by Bowersox (1992). Browsing by white-tailed deer and clipping by small mammals were recorded for surviving stems in June, July, and August of the second growing season and in August of the fourth growing season after canopy treatment. White-tailed deer were the most probable agent if stems had a rough, shredded edge (Schemnitz 1980). Small mammals were considered to be the most probable agents if stems had a sharp line of severance. Foraging damage could not be clearly determined for many of the dead stems and was not attributed to a particular agent. Overall, herbaceous vegetation covered 50% of the ground in August of the first growing season after canopy treatment (1993). To limit the effects of herbaceous competition on regeneration, plots were periodically hand-weeded in June, July, and August of the second growing season (1994). August herbaceous coverage averaged 30% in the fourth growing season (1996). At the end of the second and fourth growing seasons, the survival and height of surviving stems were recorded for direct-seeded seedlings, planted seedlings, and planted saplings.

Analysis of variance was used to test for significant ($\alpha = 0.05$) predictors of survival and height of artificial northern red oak regeneration. Main effects tested were woodlot (Bushman Hill, Herr Ridge, Powers Hill), canopy treatment (closed canopy, partially-open canopy, completely-open canopy), and fencing treatment (fence, no fence). Interactions tested were woodlot x canopy, woodlot x fence, canopy x fence, and woodlot x canopy x fence. Mean separations were performed on appropriate parameters with Tukey's method of multiple comparisons.

Results

Existing Herbaceous and Woody Plants

Herbaceous Plants

Over all inventory periods there were the same five to six species of grasses and five species of vines present in the three woodlots (Table 1). Individual plots consistently averaged 0.9 species of grasses (0 to 3 species per plot) and 2.0 species of vines (0 to 4 species per plot). There was a continuous decrease in the number of forb species from 39 one year before treatment to 29 four-years-after treatment. The pre-treatment plot average was 7.0 species (1 to 17 species per plot). This increased to 8.4 species per plot one- and two-years-after treatment but dropped to 6.0 four-years-after treatment. Bedstraw (*Galium concinnum* Torr. & A. Gray), Enchanter's nightshade (*Circaea lutetiana* L.), Virginia creeper (*Parthenocissus quinquefolia* (L.) Planch.), white snakeroot (*Eupatorium rugosum* Houtt) and wild white licorice (*Galium circaezans* Michx.) were consistently the most widely distributed and abundant plants for all inventories.

The temporal decrease in the number of forbs was due to eight species being recorded in the pre-treatment inventory only, and two species being recorded in the pre-treatment and one-year-after treatment inventories only. The initial inventory recorded beggar-ticks (*Bidens vulgata* Greene), bellwort (*Uvularia perfoliata* L.), black snakeroot (*Sanicula marilandica* L.), borage species (*Borago* spp.), pilewort (*Erechtites hieraciifolia* (L.) Raf. ex DC), and snowy orchid (*Galearis spectabilis* (L.) Raf.) on one or two plots of the 30 plot set; these were limited to one or two plants per plot. It is likely that these individuals were misidentified during pre-treatment inventory rather than being lost from the ecosystem due to post-treatment growing conditions. Buttercup (*Ranunculus* species) and skullcap (*Scutellaria spp.*) were recorded in the first two inventories but not in latter inventories. Buttercup was both frequent and abundant at Powers Hill prior to treatment, and nearly disappeared in the one-year-after treatment inventory. Skullcap was occasionally present at Bushman Hill in both the pre-treatment and one-year-after treatment inventories. Failure for these two species to be recorded in the two-years-after- and four-years-after treatment inventories is likely due to changes in growing conditions. We were not able to determine whether these changes were due to canopy or fence treatments.

These data provide a general understanding of how numbers of species varied between the partially-open and completely-open canopy treatments and between the two fencing treatments. However, results were inadequate to conduct statistical analyses. There appears to be no difference in the number of grass or vine species between partially-open and completely-open canopy treatments or between fenced and unfenced treatments for any inventory (Table 2). There also appears to be little to no fencing effect in the number of forb species for areas receiving partially-open canopy treatment. However, it appears that the completely-open canopy treatment produced an increase in the number of forb species, and greater numbers of these species in fenced rather than in unfenced treatment areas (Table 2).

Table 1. Presence[a] of individual grass, forb and vine species[b] in the inventories for the three woodlots for pre-treatment, and one-, two-, and four-years-after treatment in 1993.

Species	Pre-treatment	After Treatment One Year	After Treatment Two Years	After Treatment Four Years
		(-----------------Presence--------------------)		
Grass				
Bottle brush	Yes	Yes	Yes	Yes
Delicate Panicium	Yes	Yes	Yes	Yes
Grass Species	Yes	Yes	Yes	Yes
Panicium boscii	Yes	Yes	No	No
Panicium lanuginosum	No	No	Yes	Yes
Sedge Species	Yes	Yes	Yes	Yes
White Grass	Yes	No	No	No
Number of Species	6	5	5	5
Forb				
Bedstraw	Yes	Yes	Yes	Yes
Beggar-ticks	Yes	No	No	No
Bellwort	Yes	No	No	No
Black Snakeroot	Yes	No	No	No
Blue Violet	Yes	Yes	Yes	Yes
Borage Species	Yes	No	No	No
Buttercup	Yes	Yes	No	No
Clearweed	Yes	Yes	Yes	Yes
Common Plantain	Yes	Yes	Yes	Yes
Dandelion Species	No	Yes	Yes	Yes
Dillan's Tick Trefoil	No	No	Yes	Yes
Dogbane Species	Yes	Yes	Yes	Yes
Dwarf Cinquefoil	Yes	Yes	Yes	Yes
Early Goldenrod	Yes	Yes	No	Yes
Enchanter's Nightshade	Yes	Yes	Yes	Yes
False Solomon's Seal	Yes	No	Yes	Yes
Goldenrod Species	Yes	Yes	Yes	Yes
Horse Balm	Yes	Yes	Yes	Yes
Jack-in-the-pulpit	Yes	Yes	Yes	Yes
Jumpseed	Yes	No	No	No
Lady's Thumb	Yes	Yes	Yes	Yes
Long-bristled Smartweed	Yes	No	No	No
Lopseed	Yes	Yes	Yes	Yes
Naked-flower Trefoil	Yes	Yes	Yes	No
Panicled Tick-trefoil	Yes	Yes	Yes	Yes
Pilewort	Yes	No	No	No

Table 1. Presence[a] of individual grass, forb and vine species[b] in the inventories for the three woodlots for pre-treatment, and one-, two- and four-years-after treatment in 1993 (continued).

Species	Pre-treatment	After Treatment One Year	After Treatment Two Years	After Treatment Four Years
		(----------------Presence----	----------------	-----------)
Forb				
Pokeweed	No	Yes	Yes	Yes
Round-lobed Hepatica	Yes	Yes	Yes	Yes
Rue Anemone	Yes	Yes	Yes	Yes
Showy Orchid	Yes	No	No	No
Skullcap Species	Yes	Yes	No	No
Spotted Touch-me-not	Yes	Yes	Yes	Yes
St. John's Wort	No	Yes	No	No
Thistle Species	No	Yes	Yes	Yes
Three-seeded Mercury	Yes	Yes	No	No
Virginia Snakeroot	Yes	No	No	No
White Avens	Yes	Yes	Yes	Yes
White Snakeroot	Yes	Yes	Yes	Yes
White Vervain	Yes	Yes	Yes	Yes
Wild Comfrey	Yes	Yes	No	No
Wild Geranium	Yes	Yes	Yes	Yes
Wild Lettuce	No	No	Yes	Yes
Wild White Licorice	Yes	Yes	Yes	Yes
Yellow Agrimony	Yes	Yes	Yes	Yes
Yellow Oxalis	Yes	Yes	Yes	No
Number of Species	39	33	30	29
Vine				
Grape Species	Yes	Yes	Yes	Yes
Hog Peanut	Yes	Yes	Yes	Yes
Japanese Honeysuckle	Yes	Yes	Yes	Yes
Poison Ivy	Yes	Yes	Yes	Yes
Virginia Creeper	Yes	Yes	Yes	Yes
Number of Species	5	5	5	5

[a] Based on a species being present on at least one of 30 - 2.0 m^2 inventory plots.
[b] Scientific names are given in Appendix A.

Table 2. Average[a] number of grass, forb and vine species in partially-open and completely-open canopy and fence treatments for pre-treatment, and one-, two- and four-years-after treatment in 1993.

Herbaceous Group - Inventory Time	Partially Open		Completely Open	
	Non-fence	Fence	Non-fence	Fence
	(----------------Number of Species----------------)			
Grass				
Pre-treatment	0.8	0.9	1.0	1.0
One Year After	1.0	0.9	1.2	0.7
Two Years After	1.0	0.3	1.0	0.7
Four Years After	1.0	0.9	0.7	0.8
Forb				
Pre-treatment	7.8	6.9	6.5	6.3
One Year After	7.2	8.1	8.3	10.5
Two Years After	7.7	8.2	8.3	9.7
Four Years After	6.0	6.4	6.0	6.8
Vine				
Pre-treatment	1.9	2.1	2.3	1.7
One Year After	2.7	2.1	2.7	2.2
Two Years After	2.7	2.2	2.7	2.5
Four Years After	2.0	2.4	2.0	2.5

[a] Based on 9 plots per canopy-fence condition for the partially open and 6 plots per canopy-fence condition for the completely open.

Coverage by grass, forb and vine species groups was estimated on all 162 sample plots. Overall, average grass coverage increased from 2% at the pre-treatment inventory to 4, 8, and 13% at one-, two-, and four-years-after treatment inventories, respectively. Average forb coverage at pre-treatment was 23%, increased to 34% in the first year after treatment, then dropped to 27% in the second and fourth years after treatment. Average vine coverage was 6% in the pre-treatment growing season and increased to 16 and 24% in the first and second years after treatment, respectively. Average vine coverage dropped to 17% in the fourth year after treatment. Pre-treatment average total herbaceous coverage was 31%. Average total herbaceous coverage increased to 54 and 60% in the first and second growing seasons after treatment, respectively. Average total herbaceous coverage dropped to 54% in the fourth year after treatment.

Woodlot Effects: Differences in the pre-treatment average coverage of forb and total herbaceous plants among woodlots were significant. Average forb coverage values of 30% and 34%, respectively, at Powers Hill and Bushman Hill, were significantly different from the 4% average coverage at Herr Ridge. There was no significant difference in the pre-treatment average forb coverage at Bushman Hill and Powers Hill. These differences in forb coverage were the primary reason for the significantly different average total herbaceous coverage values among the woodlots (Table 3). Average grass, forb and total herbaceous coverage values were significantly different among the woodlots one, two and four-years-after treatment (Table 3). Vine coverage was significantly different among the woodlots two-years-after treatment only. Average grass coverage did not differ among the woodlots the first year after treatment (Table 3). Average grass coverage at Powers Hill was significantly different from both Bushman Hill and Herr Ridge the second and fourth years after treatment, however, there were no significant differences between Bushman Hill and Powers Hill (Table 3). By the fourth year after treatment average grass coverage at Powers Hill (29%) was substantially greater than the values at Bushman Hill (8%) and Herr Ridge (3%) (Table 4). The higher grass coverage at Powers Hill was mainly due to the expansion of stealth grass.

Average pre-treatment forb coverage at Herr Ridge (4%) was much lower than either Bushman Hill (34%) or Powers Hill (30%) (Table 4). Average forb coverage one-year-after treatment at Herr Ridge of 24% was a major increase over the pre-treatment value, but it was significantly different than the values for Bushman Hill (38%) and Powers Hill (40%) (Table 4). Except for Powers Hill, there was no significant difference in the two-years-after treatment average forb coverage (Table 4). Bushman Hill and Herr Ridge average forb coverage values of 32 and 28%, respectively, were significantly different than the Powers Hill average of 22% (Table 4). No significant difference was evident between Bushman Hill and Herr Ridge average forb coverage values. There were no significant differences among the woodlots in four-years-after treatment average forb coverage (Table 4).

Average total herbaceous coverage differences among the woodlots changed only slightly from pre-treatment to four-years-after treatment (Table 4). Due to forbs increase, post-treatment total herbaceous coverage at Herr Ridge increased substantially from the pre-treatment value but remained significantly different from and lower than either Bushman Hill or Powers Hill values for most inventories. Average total herbaceous coverage four-years-after treatment was 46% for Herr Ridge, 53% for Bushman Hill and 63% for Powers Hill (Table 4). Herr Ridge average

Table 3. Results of analysis of variance[a] for average grass, forb, vine and total herbaceous coverage for pre-treatment, and one-, two- and four-years-after treatment in 1993. Differences were considered to be significant (Yes) if F value had a probability of ≤0.05.

Variable - Source	Degrees of Freedom	Pre-treatment	After Treatment One Year	Two Years	Four Years
Grass					
Woodlot	2	No	No	Yes	Yes
Canopy	2	No	Yes	Yes	Yes
Fence	1	No	No	No	Yes
Woodlot x Canopy	4	No	No	Yes	Yes
Woodlot x Fence	2	No	No	No	No
Canopy x Fence	2	No	No	Yes	No
Forb					
Woodlot	2	Yes	Yes	No	Yes
Canopy	2	No	Yes	Yes	Yes
Fence	1	No	Yes	No	No
Woodlot x Canopy	4	No	No	No	Yes
Woodlot x Fence	2	No	No	No	Yes
Canopy x Fence	2	No	No	No	No
Vine					
Woodlot	2	No	No	Yes	No
Canopy	2	No	Yes	Yes	No
Fence	1	No	No	No	Yes
Woodlot x Canopy	4	No	Yes	No	Yes
Woodlot x Fence	2	No	No	No	No
Canopy x Fence	2	No	No	No	No
Total Herbaceous					
Woodlot	2	Yes	Yes	Yes	Yes
Canopy	2	Yes	Yes	Yes	Yes
Fence	1	No	Yes	No	No
Woodlot x Canopy	4	No	No	Yes	Yes
Woodlot x Fence	2	No	No	Yes	No
Canopy x Fence	2	No	No	No	No

[a] Based on 162 - 2.0 m^2 plots.

Table 4. Average[a] grass, forb, vine and total herbaceous coverage for pre-treatment, and one-, two- and four-years-after treatment in 1993, by woodlot.

Inventory Time - Woodlot	Coverage Grass	Forb	Vine	Total
	(-------------------------------	%	-------------------------------	)
Pre-treatment				
Bushman Hill	2a	34b	5a	41b
Herr Ridge	0a	4a	6a	11a
Powers Hill	4a	30b	6a	41b
One Year After				
Bushman Hill	5a	38b	15a	58b
Herr Ridge	1a	24a	16a	41a
Powers Hill	7a	40b	16a	64b
Two Years After				
Bushman Hill	7b	27a	24b	56b
Herr Ridge	2a	24a	16a	42a
Powers Hill	15c	32a	29b	67c
Four Years After				
Bushman Hill	8a	32b	14a	53ab
Herr Ridge	3a	27b	17a	46a
Powers Hill	29b	22a	19a	63b

[a] Based on 54 - 2.0 m^2 plots per woodlot. Values among woodlots within inventory time and by herbaceous group with the same letter were not significantly different from each other at the 0.05 probability level.

total herbaceous coverage was not significantly different from values at either Bushman Hill or Powers Hill.

Canopy Effects: There was a significant difference in average total herbaceous coverage for canopy treatment in the pre-treatment growing season (Table 3). Treatment units designated to receive partially-open and completely-open canopy treatments had total herbaceous coverage of 33 and 37%, respectively (Table 5). These values were significantly different from the total herbaceous coverage of 21% for those units designated for closed treatment. There was no significant difference between units designated for partially-open and completely-open canopy treatments. Canopy treatment had a significant post-treatment effect on average coverage of all herbaceous components except for grasses one-year-after treatment, forbs two-years-after treatment, and vines four-years-after treatment.

Grass coverage consistently increased after treatment more in completely-open than in partially-open and closed canopy treatments (Table 5). Average grass coverage values two and four-years-after treatment were significantly different in the completely-open compared to partially-open and closed canopy treatments (Table 5). There was a significant difference between closed and partially-open treatments two-years-after treatment but not four-years-after treatment. Four-years-after treatment, grass coverage values of 2% for the closed and 8% for the partially-open canopy treatments were significantly different from the average coverage of 29% for the completely-open canopy treatment (Table 5). There was no significant difference between closed- and partially-open canopy treatments four-years-after treatments.

Forb coverage increased rapidly following the canopy treatments, reaching maximum levels one-year-after treatment for completely-open treatments and two-years-after treatment for partially-open treatments (Table 5). Both the partially-open and completely-open canopy treatments returned to the closed value four-years-after treatment. After treatment average forb coverage was always lower in the closed- rather than the partially-open and completely-open treatments. These differences were significant for all post-treatment inventories. Partially-open and completely-open treatments were significantly different from each other in the two-years-after treatment inventory only. Average forb coverage four-years-after treatment was 19% for closed-, 32% for partially-open, and 31% for completely-open treatments (Table 5).

Vine coverage increased in all canopy treatments with inventory times, reaching a maximum two-years-after treatment (Table 5). One possible explanation for a temporal increase in vine coverage in the closed treatment was the fencing. Fenced plots in the closed treatment had 2, 5 and 8% higher vine coverage than the unfenced plots for one, two and four-years-after treatment, respectively (Table 5). Vine coverage was significantly affected by canopy treatments for inventories one- and two-years-after treatment when the higher values for completely-open were significantly different from closed- and partially-open canopy treatments. Vine coverage four-years-after treatment was not significantly different among canopy treatments (Table 3).

Prior to treatment, total herbaceous coverage values for partially-open and completely-open designated treatment areas were significantly different from closed-treatment designated areas

Table 5. Average[a] coverage of grass, forb, vine and total herbaceous species groups for pre-treatment, and one-, two- and four-years-after treatment in 1993.

Inventory Time - Woodlot	Coverage			
	Grass	Forb	Vine	Total
	(-------------------------------	%	-------------------------------	)
Pre-treatment				
Closed	0a	19a	3a	22b
Partially Open	1a	25a	7a	33ab
Completely Open	5a	24a	8a	37a
One Year After				
Closed	2a	24a	13a	38a
Partially Open	3a	35b	12a	49b
Completely Open	9a	43b	23b	75c
Two Years After				
Closed	2a	17a	16a	35a
Partially Open	6b	36b	20a	62b
Completely Open	16c	29c	33b	69b
Four Years After				
Closed	2a	19a	16a	36a
Partially Open	8a	32b	17a	53b
Completely Open	29b	31b	18a	71c

[a] Based on 54 - 2.0 m^2 plots per woodlot. Values among canopy treatments within inventory time and by herbaceous group with the same letter were not significantly different from each other at the 0.05 probability level.

(Table 5). Differences in pre-treatment total herbaceous coverage were mostly due to lower overstory stocking levels in designated partially-open and completely-open treatment areas. Average total pre-treatment herbaceous coverage in designated closed-treatment areas was 22% and increased to 38, 35 and 36% one, two and four-years-after treatment (Table 5), respectively. Average total herbaceous coverage in partially-open treatment areas increased from the pre-treatment average of 33% to 49 and 62% one- and two-years-after treatment (Table 5), respectively. Average total herbaceous coverage in partially-open treatments dropped to 53% four-years-after treatment. Completely-open treatment average total herbaceous coverage increased from the pre-treatment average of 37% to 75% one-year-after treatment, then dropped to 69 and 71% two and four-years-after treatment, respectively (Table 5). Total herbaceous coverage after treatment was significantly different among all canopy treatments one and four-years-after treatment, and significantly different between closed- and completely-open treatments two-years-after treatment (Table 3). Total herbaceous coverage in closed, partially open and completely open treatment inventories averaged 36, 53 and 71%, respectively, four-years-after treatment (Table 5).

Fence Effects: There were no significant differences in pre-treatment coverage in any herbaceous groups in areas designated to be fenced or unfenced. Average forb and total herbaceous coverage was significantly different between fenced and unfenced treatments one-year-after treatment (Table 3). Average forb coverage was 26% for unfenced and 42% for fenced; average total herbaceous was 46 and 62% for unfenced and fenced, respectively. There was no significant difference for fence treatment in the one-year-after treatment average grass or vine coverage (Table 3). After the first year following treatment forb and total herbaceous coverage in fence treatment areas became confounded by the development of woody plants. Shrub and tree seedlings in fenced plots increased in size to become more dominated by herbaceous plants than in the unfenced areas. In contrast, vine coverage continued to increase in fenced plots because they were able to climb growing shrub and tree seedlings. Vine coverage four years following treatment was 13% in unfenced and 21% in fenced plots. This difference was significant (Table 3). Grass coverage was significantly different four-years-after treatment (Table 3), due mainly to the high coverage of grass, particularly stealth grass at Powers Hill, in unfenced (16%), more so than fenced (11%) plots.

Shrub and Tree Species Seedling-sized Stems

Species Composition: The total number of pre-treatment shrub and tree species of sapling- and tree-sized stems (stems >2 cm DBH) was 25 for all woodlots. Individual woodlots ranged from 17 to 24 species. Seedling-sized vegetation pre-treatment inventories indicated 12 shrub and 13 tree species present in the three woodlots (Table 6). In the first and second growing seasons after treatment the number of shrub and tree species increased to 14 each. The number of shrub and tree species dropped to 13 and 11, respectively, in the fourth year after treatment (Table 6).

Blackberry, black-haw, grape species, redbud, rose species, and spicebush were the abundant (>0.1 stems/m^2) shrub species for all inventories (Table 6). Ash species, black cherry, elm species, mockernut hickory, and white oak were abundant tree species for all inventories (Table 6). For the less abundant species (<0.1 stems/m^2), Japanese barberry, gooseberry, sassafras,

Table 6. Overall average[a] number of shrub and tree seedling-sized stems for the three woodlots at pre-treatment, and one-, two- and four-years-after treatment in 1993.

Species	Pre-treatment	One Year After	Two Years After	Four Years After
	(-----Density of seedlings per 1.0 square meter-------)			
Shrubs				
Autumn Olive	b	0.02	0.02	b
Barberry, Japanese	0.08	0.08	0.07	0.18
Blackberry	2.26	2.56	1.81	2.27
Black-haw	0.47	0.65	0.63	0.31
Blueberry	b	0.01	0.01	b
Dogwood, flowering	0.05	0.07	0.23	0.07
Gooseberry	0.02	0.04	0.04	0.02
Grape Species	0.39	0.45	0.85	0.45
Greenbriar	0.01	b	b	0.01
Redbud	0.54	0.64	0.82	0.54
Rose Species	0.17	0.20	0.18	0.48
Serviceberry	b	0.01	0.05	0.05
Spicebush	1.65	1.80	1.90	1.90
Sassafras	0.02	0.04	0.10	0.07
Witch-hazel	0.01	0.04	0.02	0.07
Total Shrubs[c]	5.65	6.61	6.73	6.41
Trees				
Ash Species	2.01	2.46	2.16	0.78
Black-gum	0.23	0.10	0.09	b
Cedar, Eastern Red	0.01	0.02	0.01	b
Cherry, Black	0.23	0.24	0.23	0.19
Cherry, Mazzard	0.03	0.10	0.16	0.01
Elm Species	0.46	0.54	0.42	0.11
Hickory, Mockernut	0.13	0.17	0.21	0.23
Hickory, Pignut	b	b	0.01	0.02
Locust, Black	0.03	0.01	b	b
Maple, Red	0.03	0.05	0.13	0.01
Maple, Sugar	0.01	0.01	0.01	b
Oak, Black	0.05	0.03	0.04	0.10
Oak, Northern Red	0.04	0.06	0.06	0.02
Oak, White	0.76	0.77	0.87	0.07
Yellow poplar	b	0.86	1.57	0.18
Total Trees[c]	4.04	5.44	6.00	1.74

[a] Based on 162 - 2.0 m^2 plots. [b] No seedling-sized stems were inventoried.
[C] Summation of individual species values may not equal total due to rounding.

witch-hazel, mazzard cherry, red maple, black oak, and northern red oak were consistently present in all inventories. Greenbriar was a rare species before treatment, was not recorded one or two-years-after treatment, but did re-appear four-years-after treatment. Serviceberry and blueberry were not in the pre-treatment record but were recorded in the first growing season after canopy treatment and continued to be present the second and fourth year after treatment. Black locust was present on the inventory plots before and one-year-after canopy treatment but was not present two or four-years-after treatment. Yellow poplar was not present before canopy treatment but was recorded in all post-treatment inventories.

Overall average numbers of pre-treatment seedling-sized species per 2.0 m^2 were 2.3 for shrub species, 2.4 for tree species and 4.7 for total species. The average number of shrub, tree and total seedling-sized species per 2.0 m^2 increased to 2.5, 2.9 and 5.4, respectively, one-year-after canopy treatment and 2.9, 2.9 and 5.8, respectively, two-years-after canopy treatment. From two to four-years-after treatment, the average number of shrub, tree and total seedling-sized species per 2.0 m^2 plot decreased to 2.2, 1.4 and 3.6, respectively. The main reason for the 0.7 drop in the average number of shrub species per 2.0 m^2 plot between two and four-years-after treatment was the reduction in the occurrence of black-haw, redbud and grape. Black-haw, redbud, and grape were recorded in the fourth year after treatment on 57, 58 and 64%, respectively, of the plots that they were recorded on in the second year after treatment. The decline of 1.5 in the average number of tree species per 2.0 m^2 plot was due to the lower occurrence of elm, white oak, and yellow poplar. Elm, white oak, and yellow poplar were recorded in the fourth year after treatment on 31, 19 and 26%, respectively, of the plots that they were recorded on in the second year after treatment.

In the fourth-year-after treatment inventory, the average number of tree and total seedling-sized species per 2.0 m^2 plot was significantly different among woodlots for all inventories (Table 7). The lower average number of species per 2.0 m^2 plot for all groups at Herr Ridge was consistently and significantly lower than Bushman Hill and Powers Hill (Table 8). Pre-treatment higher average numbers of shrub, tree and total seedling-sized species per 2.0 m^2 plot at Bushman Hill were significantly different from Powers Hill (Table 8). There were no significant post-treatment differences between Bushman Hill and Powers Hill in the average number of shrub, tree or total seedling-sized species per 2.0 m^2 plot. There also were significant woodlot x canopy differences for the average number of shrub, tree and total seedling-sized species for all post-treatment inventories (Table 7). These significant interactions were primarily due to woodlot differences in number of species per 2.0 m^2 for the partially-open treatment. At Bushman Hill there generally were no significant differences among the canopy treatments for any of the species groups. There was a general trend at Herr Ridge of having a lower number of species per 2.0 m^2 for the partially-open treatment than either the closed or completely-open treatment. Conversely, having a higher number of species per 2.0 m^2 for the partially-open treatment rather than either the closed or completely-open treatment was the general trend at Powers Hill. There were no known reasons for these woodlot differences.

Density: There was an overall average of 5.7 shrub seedling-sized stems/m^2 and 4.0 tree seedling-sized stems/m^2 in the growing season before treatments (Table 6). Blackberry had 2.3 seedling-sized stems/m^2 and spicebush had 1.7 seedling-sized stems/m^2, which accounted for the

Table 7. Results of analysis of variance of the average number of species of seedling-sized shrub, tree and total stems for selected factors at pre-treatment, and one-, two- and four-years-after treatment in 1993. Differences were considered to be significant (Yes) if the F value had a probability of ≤ 0.05.

Inventory Time - Factor	Degrees of Freedom	Shrub	Tree	Total
Pre-treatment				
Woodlot	2	Yes	Yes	Yes
Canopy	2	No	No	No
Fence	1	No	No	No
Woodlot x Canopy	4	No	No	No
Canopy x Fence	2	No	No	No
One Year After				
Woodlot	2	Yes	Yes	Yes
Canopy	2	No	No	No
Fence	1	No	No	No
Woodlot x Canopy	4	Yes	Yes	Yes
Canopy x Fence	2	No	No	No
Two Years After				
Woodlot	2	Yes	Yes	Yes
Canopy	2	No	No	No
Fence	1	No	No	No
Woodlot x Canopy	4	Yes	Yes	Yes
Canopy x Fence	2	No	No	No
Four Years After				
Woodlot	2	No	Yes	Yes
Canopy	2	Yes	Yes	Yes
Fence	1	No	No	No
Woodlot x Canopy	4	Yes	Yes	Yes
Canopy x Fence	2	No	No	No

Table 8. Average[a] number of species of seedling-sized shrub, tree and total stems per 2.0 m^2 plot for the three woodlots at pre-treatment, and one-, two- and four-years-after treatment in 1993.

Inventory Time - Woodlot	Shrub	Tree	Total
	(-------------Number of species/2.0 m^2 plot---------)		
Pre-treatment			
Bushman Hill	3.2c	3.4c	6.6c
Herr Ridge	1.3a	1.5a	2.8a
Powers Hill	2.5b	2.2b	4.7b
One Year After			
Bushman Hill	3.3b	3.6b	6.9b
Herr Ridge	1.4a	1.7a	3.1a
Powers Hill	2.9b	3.3b	6.2b
Two Years After			
Bushman Hill	3.6b	3.6b	7.2b
Herr Ridge	1.6a	1.9a	3.5a
Powers Hill	3.4b	3.4b	6.8b
Four Years After			
Bushman Hill	2.6b	1.3a	3.9b
Herr Ridge	1.4a	1.4a	2.8a
Powers Hill	2.8b	1.4a	4.2b

[a] Based on 54 - 2.0 m^2 plots per woodlot. Values among woodlot within inventory time and species group with the same letter were not significantly different from each other at the 0.05 probability level. Total may not equal the sum of shrub and tree due to rounding.

majority of shrub seedling-sized stems. Ash dominated the tree species with an average of 2.0 seedling-sized stems/m^2. There was an average of 0.9 seedling-sized stems/m^2 for all oak species with white oak being the most dominant. All seedling-sized stems were dominated by stems in the ≤25 cm height class (Table 9). Over all woodlots, canopy, and fence treatments 77% of the shrub seedling-sized stems and 92% of the tree seedling-sized stems were ≤25 cm tall.

In the first growing season after treatment there was an increase in overall average density of shrub and tree seedling-sized stems to 6.6/m^2 and 5.4/m^2, respectively. The average number of seedling-sized blackberry (2.6/m^2) and spicebush (1.8/m^2) stems accounted for the majority of shrub seedlings. Ash had the highest average number of tree seedling-sized stems with 2.5/m^2. All oak species and yellow poplar, each, averaged 0.9 seedling-sized stems/m^2. No yellow poplar seedling-sized stems were recorded in the pre-treatment inventories. Most seedling-sized stems in the first growing season after treatment were in the ≤25 cm class (Table 9). Pooled over all treatments, 66% of shrub seedling-sized stems and 88% of tree seedling-sized stems were ≤25 cm tall in the first growing season after canopy treatment.

Overall average density of shrub and seedling-sized stems continued to increase in the second growing season after treatment. In the second growing season after treatment there was an overall average number of 7.0 shrub seedling-sized stems/m^2 and 6.0 tree seedling-sized stems/m^2. Blackberry (1.8/m^2) and spicebush (1.9/m^2) continued to account for the majority of shrub seedling-sized stems. Ash had the highest average density of tree seedling-sized stems with 2.4/m^2 and yellow poplar was second highest with 1.6 stems/m^2. All oak species combined averaged 1.0 seedling-sized stems/m^2. Most of the seedling-sized stems in the second growing season after canopy treatment were in the ≤25 cm class (Table 9). Overall, 53% of the shrub seedling-sized stems and 79% of the tree seedling-sized stems were ≤25 cm tall.

Overall average density of shrub and seedling-sized stems in the fourth year after treatment decreased from the second growing season after treatment density. Overall average density of shrub seedling-sized stems was 6.4/m^2 and the average density of tree seedling-sized stems/m^2 was 1.7 the fourth year after treatment. Blackberry (2.3/m^2) and spicebush (1.9/m^2) continued to account for the majority of shrub seedling-sized stems. Although ash and yellow poplar seedling-sized stem density dropped substantially, they continued to be the most abundant species. Ash had the highest average density of tree seedling-sized stems with 0.8/m^2 and yellow poplar was second highest with 0.2 stems/m^2. All oak species averaged 0.2 seedling-sized stems/m^2. Between the second and fourth years after treatment there were substantial changes in height structure of seedling-sized stems. Most of the seedling-sized stems in the fourth growing season after treatment were in the >25 cm class (Table 9). Overall, 68% of the shrub seedling-sized stems and 52% of the tree seedling-sized stems were >25 cm tall.

Woodlot Effects: Woodlot was consistently a significant factor of average density of shrub, tree and total seedling-sized stems, except for shrub seedling-sized stems in pre-treatment and first-year-after treatment inventories (Table 10). Pooled over woodlots, average density of shrub seedling-sized stems increased from 5.6/m^2 to 6.6/m^2 between pre-treatment and first growing season after canopy treatment inventories (Table 11). In the second and fourth years after treatment, average density of shrub seedling-sized stems at Bushman Hill and Powers Hill

Table 9. Average[a] density of shrub, tree and total seedling-sized stems by height class for the three woodlots at pre-treatment, and one-, two- and four-years-after treatment in 1993.

Inventory Time - Height Class	Shrub	Tree	Total
	(-----Density of seedlings per 1.0 square meter-----)		
Pre-treatment			
1-25 cm	4.34c	3.70c	8.04c
26-50 cm	1.03b	0.27b	1.30b
51- 75 cm	0.17a	0.06a	0.23a
76-100 cm	0.06a	0.02a	0.08a
101-125 cm	0.04a	0.00a	0.04a
126-150 cm	0.01a	0.00a	0.01a
One Year After			
1-25 cm	4.39d	4.84b	9.23c
26-50 cm	1.47c	0.48a	1.95b
51- 75 cm	0.53b	0.13a	0.66a
76-100 cm	0.17ab	0.05a	0.22a
101-125 cm	0.06ab	0.02a	0.08a
126-150 cm	0.01ab	0.00a	0.01a
Two Years After			
1-25 cm	3.62e	4.74c	8.36c
26-50 cm	1.89d	0.85b	2.74b
51- 75 cm	0.75c	0.23ab	0.98a
76-100 cm	0.31b	0.09ab	0.40a
101-125 cm	0.12a	0.05a	0.17a
126-150 cm	0.08a	0.03a	0.11a
Four Years After			
1-25 cm	2.10d	0.86c	2.96d
26-50 cm	1.61c	0.41b	2.02c
51- 75 cm	1.00b	0.14a	1.14b
76-100 cm	0.59ab	0.05a	0.64ab
101-125 cm	0.39a	0.05a	0.43a
126-150 cm	0.73ab	0.23ab	0.96ab

[a] Based on 162 - 2.0 m^2 plots. Values among height class within inventory time and by species group with the same letter were not significantly different from each other at the 0.05 probability level. Total may not equal the sum of shrub and tree due to rounding.

Table 10. Results of analysis of variance of the average density shrub, tree and total seedling-sized stems for selected factors at pre-treatment, and one-, two- and four-years-after treatment in 1993. Differences were considered to be significant (Yes) if the F value had a probability of ≤0.05.

Inventory Time -Factor	Degrees of Freedom	Shrub	Tree	Total
Pre-treatment				
Woodlot	2	No	Yes	Yes
Canopy	2	No	No	No
Fence	1	Yes	No	Yes
Woodlot x Canopy	4	No	Yes	Yes
Canopy x Fence	2	No	No	No
One Year After				
Woodlot	2	No	Yes	Yes
Canopy	2	No	No	No
Fence	1	No	No	No
Woodlot x Canopy	4	No	No	No
Canopy x Fence	2	No	No	No
Two Years After				
Woodlot	2	Yes	Yes	Yes
Canopy	2	No	Yes	Yes
Fence	1	No	No	No
Woodlot x Canopy	4	Yes	No	Yes
Canopy x Fence	2	Yes	No	No
Four Years After				
Woodlot	2	Yes	No	Yes
Canopy	2	No	Yes	No
Fence	1	Yes	Yes	Yes
Woodlot x Canopy	4	Yes	Yes	Yes
Canopy x Fence	2	No	No	No

Table 11. Average[a] density of shrub, tree and total seedling-sized stems for the three woodlots at pre-treatment, and one-, two- and four-years-after treatment in 1993.

Inventory Time - Woodlot	Shrub	Tree	Total
	(---Density of seedlings per 1.0 square meter-----)		
Pre-treatment			
Bushman Hill	5.8a	6.5c	12.3c
Herr Ridge	5.6a	1.3a	6.9a
Powers Hill	5.4a	4.2b	9.6b
One Year After			
Bushman Hill	6.7a	8.6c	15.3b
Herr Ridge	6.3a	1.5a	7.8a
Powers Hill	7.0a	6.4b	13.4b
Two Years After			
Bushman Hill	7.6b	8.9b	16.5b
Herr Ridge	4.7a	1.6a	6.3a
Powers Hill	8.0b	7.5b	15.5b
Four Years After			
Bushman Hill	7.6b	1.7a	9.3b
Herr Ridge	4.3a	1.4a	5.7a
Powers Hill	7.4b	2.1a	9.5b

[a] Based on 54 - 2.0 m^2 plots per woodlot. Values among woodlots within inventory time and by species group with the same letter were not significantly different from each other at the 0.05 probability level. Total may not equal the sum of shrub and tree due to rounding.

continued to be higher than the pre-treatment values (Table 11). In contrast, the average second and fourth year after treatment shrub seedling-sized stem densities at Herr Ridge dropped below the pre-treatment value. Average density of shrub seedling-sized stems two-years-after treatment at Herr Ridge (4.7/m^2) was significantly different from either Bushman Hill (7.6/m^2) or Powers Hill (8.0/m^2). Average density of shrub seedling-sized stems four-years-after treatment at Herr Ridge (4.3/m^2) was significantly different from either Bushman Hill (7.6/m^2) or Powers Hill (7.4/m^2). There was no significant difference between the average density of shrub seedling-sized stems at Bushman Hill and Powers Hill for two or four-years-after treatment.

The average pre-treatment densities of tree seedling-sized stems were significantly different among Bushman Hill (6.5/m^2), Herr Ridge (1.3/m^2) and Powers Hill (4.3/m^2) (Table 11). In the first year after treatment, average densities of tree seedling-sized stems for Bushman Hill (8.6/m^2), Herr Ridge (1.5/m^2) and Powers Hill (6.3/m^2) were again significantly different from each other. Average density of tree seedling-sized stems among the woodlots continued to increase in the second year after treatment. Average density of tree seedling-sized stems two-years-after treatment at Herr Ridge (1.6/m^2) was significantly different from Bushman Hill (8.9/m^2) and Powers Hill (7.5/m^2); there was no significant difference between the average two-years-after treatment density of tree seedling-sized stems Bushman Hill and Powers Hill. There was a major decline in the average density of tree seedling-sized stems between two and four-years-after treatment (Table 11). There was no significant difference in the average four-years-after treatment density of tree seedling-sized stems among the woodlots. Pooled over woodlot, average four-years-after treatment density of tree seedling-sized stems was 1.7/m^2.

Average density of total seedling-sized stems among the woodlots followed a pattern similar to the tree seedling-sized stems densities in the pre-treatment and one- and two-years-after treatment, and the average density of shrub seedling-sized stems in the fourth year after treatment (Tables 10 and 11).

Canopy Effects: Except for the average density of tree and total seedling-sized stems two-years-after canopy treatment and average density of tree seedling-sized stems four-years-after canopy treatment, there were no significant differences in the average density of shrub, tree or total seedling-sized stems among the three canopy treatments for any of the inventories (Table 10). The two-years-after treatment average densities of tree seedling-sized stems in the closed (4.4/m^2) and partially open (7.1/m^2) canopy treatments were significantly different from each other but neither were significantly different from the completely open (6.6/m^2) canopy treatment (Table 12). Average density of total seedling-sized stems two-years-after canopy treatment in the closed canopy (10.8/m^2) was significantly different from the completely open (14.9/m^2) canopy treatment but not from the partially open (12.5/m^2) canopy treatment (Table 12). There was no significant difference between the partially open and completely open canopy treatments. In the fourth year after canopy treatment, average densities of tree seedling-sized stems in closed (2.1/m^2) and completely open (1.2/ m^2) canopy treatments were significantly different from each other but neither were significantly different from the partially open (1.9/m^2) canopy treatment.

Fence Effects: Fencing did not significantly influence the average densities of shrub, tree or total seedling-sized stems prior to, and one- and two-years-after treatment, except for shrub and total

Table 12. Average[a] density of shrub, tree and total seedling-sized stems for the three canopy treatments at pre-treatment, and one-, two- and four-years-after treatment in 1993.

Inventory Time - Canopy Treatment	Shrub	Tree	Total
	(---Density of seedlings per 1.0 square meter-----)		
Pre-treatment			
Closed	5.9a	3.8a	9.7a
Partially Open	5.5a	4.3a	9.8a
Completely Open	5.4a	3.9a	9.3a
One Year After			
Closed	6.7a	4.5a	11.2a
Partially Open	6.9a	6.3a	13.2a
Completely Open	6.3a	5.5a	11.8a
Two Years After			
Closed	6.4a	4.4a	10.8a
Partially Open	7.8a	7.1b	14.9b
Completely Open	5.9a	6.6ab	12.5ab
Four Years After			
Closed	5.6a	2.1b	7.7a
Partially Open	6.9a	1.9ab	8.8a
Completely Open	6.8a	1.2a	8.0a

[a] Based on 54 plots per canopy treatment. Values among canopy treatments within inventory time and by species group with the same letter were not significantly different from each other at the 0.05 probability level. Total may not equal the sum of shrub and tree due to rounding.

seedling-sized stems in the year before canopy treatment (Table 10). Average densities of pre-treatment unfenced shrub ($4.8/m^2$) and total ($8.6/m^2$) seedling-sized stems were significantly different from fenced shrub ($6.4/m^2$) and total ($10.5/m^2$) seedling-sized stems; these differences were due to random designation of the plots to be fenced before treatments were conducted (Table 13).

Fencing significantly influenced the average densities of shrub, tree or total seedling-sized stems four-years-after treatment (Table 10). Average densities of four-years-after treatment unfenced shrub ($5.8/m^2$), tree ($1.5/m^2$) and total ($7.3/m^2$) seedling-sized stems were significantly different from the fenced shrub ($7.0/m^2$), tree ($2.0/m^2$) and total ($9.0/m^2$) values (Table 13).

Density by Height Class: Distribution of seedling-sized stems among height classes for all inventories was skewed to the smaller height classes (Table 9). On many of the plots there were no seedling-sized stems >50 cm tall, therefore data in the five taller height classes were pooled into a 26-150 cm class for the statistical analyses. Effects of woodlot, canopy treatment and fence treatment were also analyzed by adding height class (1-25 and 26-150 cm) to the model. The main effect results of these analyses (Table 14) were the same as for the analyses for all seedling-sized stems regardless of height class (Table 10) with two exceptions. The first exception was that there was no significant difference due to fence for the average density of total seedling-sized stems in the year before canopy treatment. The second exception was at four-years-after treatment when fence was not a significant factor in the density of tree seedling-sized stems. Height class was a significant factor in the average density of seedling-sized stems for all species groups at all inventory dates, except for shrubs in the second year after canopy treatment and trees in the fourth year after treatment (Table 14). Woodlot by height class, canopy treatment by height class, and fence treatment by height class effects were of particular interest in these analyses.

The effect of woodlot on the density of seedling-sized stems by height class was significant for all analyses, except shrubs at two-years-after treatment and trees at four-years-after treatment (Table 14). In general, the majority of the pre-treatment and one-year-after treatment seedling-sized stems for shrubs were in the 1-25 cm height class (Table 15). This height structure started to change at two-years-after treatment. By four-years-after treatment density was greater in the 26-150 cm height class than in the 1-25 cm height class. There was similar temporal change in the tree species height structure but the initial difference was greater than for the shrub species and by four-years-after treatment the densities in each height class were about equal. Within these general trends there were some differences among the woodlots. Compared to Herr Ridge and Powers Hill, there were higher densities of 1-25 cm height class shrub stems and lower densities of 26-150 cm height class stems at Bushman Hill for pre-treatment, and one- and two-years-after treatment (Table 15). At four-years-after treatment, Bushman Hill and Powers Hill had higher densities in the 26-150 cm height class than Herr Ridge (Table 15). The densities of tree seedling-sized stems in the 1-25 cm height class at Bushman Hill and Powers Hill were substantially greater than at Herr Ridge for pre-treatment, and one- and two-years-after treatment. Densities of tree seedling-sized stems in the 26-150 cm height class for these inventories were similar for all woodlots (Table 15). At four-years-after treatment, there were no differences in the tree seedling-sized height structure among the woodlots (Table 15).

Table 13. Average[a] density of shrub, tree and total seedling-sized stems for the fencing treatments at pre-treatment, and one-, two- and four-years-after treatment in 1993.

Inventory Time - Fence Treatment	Shrub	Tree	Total
	(---Density of seedlings per 1.0 square meter-----)		
Pre-treatment			
Unfenced	4.8a	3.9a	8.6a
Fenced	6.4b	4.1a	10.5b
One Year After			
Unfenced	6.1a	5.4a	11.5a
Fenced	7.1a	5.5a	12.6a
Two Years After			
Unfenced	7.1a	6.0a	13.1a
Fenced	6.3a	5.9a	12.2a
Four Years After			
Unfenced	5.8a	1.5a	7.3a
Fenced	7.0b	2.0a	9.0b

[a] Based on 81 plots per fencing treatment. Values between fence treatment within inventory time and by species group with the same letter were not significantly different from each other at the 0.05 probability level. Total may not equal the sum of shrub and tree due to rounding.

Table 14. Results of analysis of variance of average density of shrub, tree and total seedling-sized stems per height class for selected factors at pre-treatment, and one- and two-years-after treatment in 1993. Differences were considered to be significant (Yes) if the F value had a probability of ≤0.05.

Inventory Time - Factor	Degrees of Freedom	Shrub	Tree	Total
Pre-treatment				
Woodlot	2	No	Yes	Yes
Canopy	2	No	No	No
Fence	1	Yes	No	No
Height	1	Yes	Yes	Yes
Woodlot x Height	4	Yes	Yes	Yes
Canopy x Height	2	No	No	No
Fence x Height	1	Yes	No	No
One Year After				
Woodlot	2	No	Yes	Yes
Canopy	2	No	No	No
Fence	1	No	No	No
Height	1	Yes	Yes	Yes
Woodlot x Height	4	Yes	Yes	Yes
Canopy x Height	2	No	Yes	Yes
Fence x Height	1	No	No	No
Two Years After				
Woodlot	2	Yes	Yes	Yes
Canopy	2	No	Yes	Yes
Fence	1	No	No	No
Height	1	No	Yes	Yes
Woodlot x Height	4	Yes	Yes	Yes
Canopy x Height	2	Yes	Yes	Yes
Fence x Height	1	Yes	Yes	Yes
Four Years After				
Woodlot	2	Yes	No	Yes
Canopy	2	No	Yes	No
Fence	1	Yes	No	Yes
Height	1	Yes	No	Yes
Woodlot x Height	4	Yes	Yes	Yes
Canopy x Height	2	Yes	Yes	Yes
Fence x Height	1	Yes	No	Yes

Table 15. Average[a] density of shrub, tree and total seedling-sized stems for the three woodlots by height class at pre-treatment, and one-, two- and four-years-after treatment in 1993

Inventory Time - Woodlot	Shrub Height Class		Tree Height Class		Total Height Class	
	1-25 cm	26-150 cm	1-25 cm	26-150 cm	1-25 cm	26-150 cm
	(--------------Density of seedlings per 1.0 square meter---------------)					
Pre-treatment						
Bushman Hill	5.2b	0.8a	6.3c	0.2a	11.5b	1.1a
Herr Ridge	3.9b	1.6a	0.7a	0.5a	4.7b	2.1a
Powers Hill	3.9b	1.5a	4.1b	0.3a	8.0b	1.8a
One Year After						
Bushman Hill	5.0c	1.7a	7.9c	0.7a	12.9c	2.4a
Herr Ridge	3.7bc	2.5ab	0.8a	0.7a	4.5b	3.2a
Powers Hill	4.5bc	2.5ab	5.9b	0.6a	10.4c	3.1a
Two Years After						
Bushman Hill	3.9b	3.6ab	7.2b	1.7a	11.1b	5.3a
Herr Ridge	2.3a	2.4ab	0.7a	1.0a	3.0a	3.4a
Powers Hill	4.6b	3.4ab	6.4b	1.1a	11.0c	4.6a
Four Years After						
Bushman Hill	2.8a	4.7b	1.1b	0.7b	3.9b	5.4bc
Herr Ridge	1.7a	2.6a	0.5a	0.9b	2.1a	3.5ab
Powers Hill	1.8a	5.6b	1.0b	1.0b	2.8a	6.7c

[a] Based on 54 - 2.0 m^2 plots per woodlot. Values among woodlots treatment and height class within inventory time and by species group with the same letter were not significantly different from each other at the 0.05 probability level. Total may not equal the sum of shrub and tree due to rounding.

Effect of canopy treatment on the density of seedling-sized stems by height class was not a significant pre-treatment factor (Table 14). This interaction was significant for all post-treatment analyses except shrubs at one-year-after treatment (Table 14). A majority of the shrub and tree seedling-sized stems were in the 1-25 cm height class until four-years-after treatment (Table 16). At this inventory, there was a significant difference in the shrub and total but not in the tree species group (Table 16). The greatest change in the density by height class for shrub seedling-sized stems occurred in the completely open treatment. There was an average of 5.4 shrub seedling-sized stems in the 26-150 cm height class, which was significantly different from all other treatment-size combinations (Table 16). Although there was no significant difference in the density by height class for the tree seedling-sized stems at four-years-after treatment, this represents a substantial change in height structure from the pre-treatment and one-year-after treatment inventories. In these earlier inventories there was a 10 to 20 factor advantage for the 1-25 cm height class over the 26-150 cm class (Table 16).

The effect of fence treatment on the density of seedling-sized stems by height class was a significant factor for pre-treatment shrubs, two-years-after treatment shrubs, trees and total, and four-years-after treatment shrubs and total (Table 14). The general effect of fence on the density of seedling-sized stems by height class was to shift from initial density dominance by the 1-25 cm height class to a four year after treatment density predominance by the 26-150 height class (Table 17). The change in four-years-after treatment density by height class was greatest for fenced shrub seeding-sized stems, which was significantly different from all other treatment-size combinations (Table 17). There was a similar advantage for fenced tree seedling-sized stems but the difference was not significant. Fence treatment had no consistent effect on the density of 1-25 cm height class shrub, tree or total seedling-sized stems.

Canopy x height class interaction for average density of shrub, tree and total seedling-sized stems was not significant in the year before canopy treatments (Table 14). At that time 80% or more of the seedling-sized stems were in the 1-25 cm height class and this relative difference did not vary among canopy treatments. Canopy x height class interaction was not significant for average density of shrub or tree seedling-sized stems but was significantly different for total seedling-sized stems in the first growing season after canopy treatment (Table 12). In the first growing season after treatment there were small decreases in the relative density of 1-25 cm height class seedling-sized stems and corresponding small increases in the relative density of seedling-sized stems in the 26-150 cm height class. Canopy x height interactions were significant for the average density of shrub, tree and total seedling-sized stems two and four-years-after canopy treatment (Table 14). Increases in the relative density of seedling-sized stems in the 26-150 cm height classes for these inventories were different among the canopy treatments. The greatest increases in the relative density of shrub, tree and total seedling-sized stems in the 26-150 height classes were in the completely open canopy treatments. At four-years-after canopy treatment 79% of shrub seedling-sized stems in the completely open canopy treatment were in the 26-150 cm height class as compared to 56 and 63% for closed and partially open canopy treatments, respectively. The relative number of tree seedling-sized stems in the completely open canopy treatment at four-years-after canopy treatment was 91% as compared to 36 and 45% for closed and partially open canopy treatments, respectively.

Table 16. Average[a] density of shrub, tree and total seedling-sized stems for the three canopy treatments by height class at pre-treatment, and one-, two- and four-years-after treatment in 1993.

Inventory Time - Canopy Treatment	Shrub Height Class 1-25 cm	Shrub Height Class 26-150 cm	Tree Height Class 1-25 cm	Tree Height Class 26-150 cm	Total Height Class 1-25 cm	Total Height Class 26-150 cm
	(--------------Density of seedlings per 1.0 square meter---------------)					
Pre-treatment						
Closed	4.6b	1.3a	3.5b	0.5a	8.1b	1.8a
Partially Open	4.5b	1.1a	4.1b	0.2a	8.5b	1.3a
Completely Open	4.0b	1.5a	3.5b	0.3a	7.5b	1.9a
One Year After						
Closed	4.4b	2.2a	3.9b	0.6a	8.4b	2.8a
Partially Open	4.9b	2.0a	6.0c	0.5a	10.9c	2.6a
Completely Open	3.8b	2.5a	4.6b	0.9a	8.4b	3.4a
Two Years After						
Closed	3.7ab	2.8ab	3.5b	0.8a	7.2b	3.6a
Partially Open	4.8b	3.0ab	6.1c	1.0a	10.9c	4.1a
Completely Open	2.4a	3.6ab	4.6b	2.0ab	7.0b	5.6a
Four Years After						
Closed	2.4a	3.1ab	1.4b	0.8b	3.8b	3.9b
Partially Open	2.5a	4.4b	1.1b	0.9b	3.5b	5.3bc
Completely Open	1.4a	5.4c	0.1a	1.0b	1.6a	6.4c

[a] Based on 54 - 2.0 m^2 plots per woodlot. Values among canopy treatment and height class within inventory time and by species group with the same letter were not significantly different from each other at the 0.05 probability level. Total may not equal the sum of shrub and tree due to rounding.

Table 17. Average[a] density of shrub, tree and total seedling-sized stems for the two fence treatments by height class at pre-treatment, and one-, two- and four-years-after treatment in 1993.

Inventory Time - Fence Treatment	Shrub Height Class 1-25 cm	Shrub Height Class 26-150 cm	Tree Height Class 1-25 cm	Tree Height Class 26-150 cm	Total Height Class 1-25 cm	Total Height Class 26-150 cm
	(--------------Density of seedlings per 1.0 square meter---------------)					
Pre-treatment						
No Fence	3.7b	1.3a	3.6b	0.4a	7.3b	1.6a
Fence	5.0c	1.4a	3.7b	0.3a	8.8b	1.7a
One Year After						
No Fence	4.3c	1.8a	5.0b	0.5a	9.2b	2.3a
Fence	4.5c	2.7a	4.7b	0.9a	9.2b	3.6a
Two Years After						
No Fence	4.5b	2.6a	5.4b	0.8a	9.9d	3.4a
Fence	2.7a	3.7b	4.1c	1.8b	6.8c	5.5b
Four Years After						
No Fence	2.2a	3.6b	0.9a	0.6a	3.0a	4.3b
Fence	2.0a	5.0c	0.9a	1.1a	2.9a	6.1c

[a] Based on 54 - 2.0 m^2 plots per woodlot. Values among fence treatment and height class within inventory time and by species group with the same letter were not significantly different from each other at the 0.05 probability level. Total may not equal the sum of shrub and tree due to rounding.

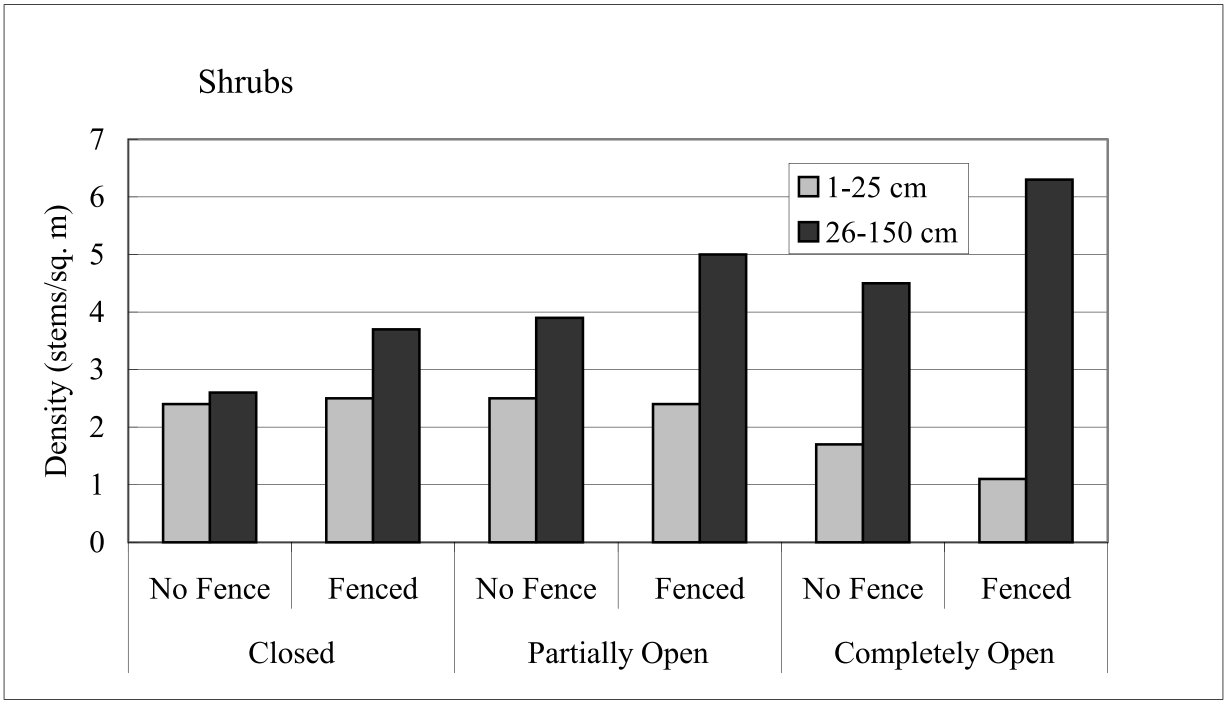
Fencing had no significant differential effect on the average density of tree and total seedling-sized stems by height class until the second growing season after canopy treatment (Table 14). Prior to canopy treatment, fence x height class interaction was significant for the average density of shrub seedling-sized stems but was not significant for tree or total seedling-sized stems (Table 14). Less than 30% of the seedling-sized stems were in the 26-150 cm height classes for all species groups. The fence x height class interaction in the first year after canopy treatment was not significant for the average density of shrub, tree or total species seedling-sized stems. At that time, there were no increases in relative density of seedling-sized stems in the unfenced 26-150 cm height classes but there were small increases in the fenced 26-150 cm height classes. Fence x height interactions were significant for average density of shrub, tree and total seedling-sized stems two-years-after canopy treatment. In the second growing season after canopy treatment <30% of unfenced seedling-sized stems for all species groups were in the 26-150 cm height classes. In contrast, 60% of fenced shrub seedling-sized stems, 30% of fenced tree seedling-sized stems and 50% of fenced total seedling-sized stems were in the 26-150 cm height classes. The relative number of shrub and tree seedling-sized stems in the 26-150 cm height classes in fenced areas at four-years-after canopy treatment was 71 and 55% as compared to 38 and 40% for unfenced areas, respectively.

Prior to treatment these woodlots had an overall average density of 4.3 and 1.3/m^2 seedling-sized shrub stems in the 1-25 and 26-150 cm height class, respectively. The pre-treatment inventory also recorded 3.7 and 0.3/m^2 seedling-sized tree stems, in the 1-25 and 26-150 cm height class, respectively. Four-years-after treatment there were average densities of seedling-sized stems in the 1-25 cm and 26-150 cm height classes of 2.1 and 4.3/m^2 for shrubs, respectively, and 0.9/m^2 for trees in both height classes. Over all woodlots, the densities of shrub and tree seedling-sized stems in the 1-25 cm and 26-150 cm height classes were dependent on canopy treatment (Figure 1). Compared to unfenced, fenced increased the density of shrub seedling-sized stems in the 26-150 height class from 2.6 to 3.7/m^2 in the closed canopy, 3.9 to 5.0/m^2 in the partially open canopy and 4.5 to 6.3/m^2 in the completely open canopy (Figure 1). Compared to unfenced, fenced increased the density of tree seedling-sized stems in the 26-150 height class from 0.4 to 1.1/m^2 in closed canopy, 0.8 to 1.0/m^2 in partially open canopy and from 0.8 to 1.2/m^2 in completely open canopy (Figure 1).

Recruitment of Shrubs and Trees

Average densities of shrub and tree seedlings that germinated after canopy treatments and survived to the time of inventory are presented in Table 18. Across all 2.0 m^2 plots, 6, 8, and 8 shrub seedling species and 10, 12, and 9 tree seedling species were recorded at the end of one, two, and four-years-after canopy treatments, respectively. No serviceberry (*Amelanchier arborea* (Michx. f.) Fern), blackberry/raspberry (*Rubus* spp.), sweet birch (*Betula lenta* L.), or black oak seedlings were recorded until the second growing season after treatments. By the fourth growing season, no sweet birch, black-gum (*Nyssa sylvatica* Marsh.), or mazzard cherry germinants had survived.

Total density of shrubs recruitment seedlings was 2.10 and 2.13/m^2 at one and two-years-after canopy treatments, respectively (Table 18). The most abundant species were grape and redbud.



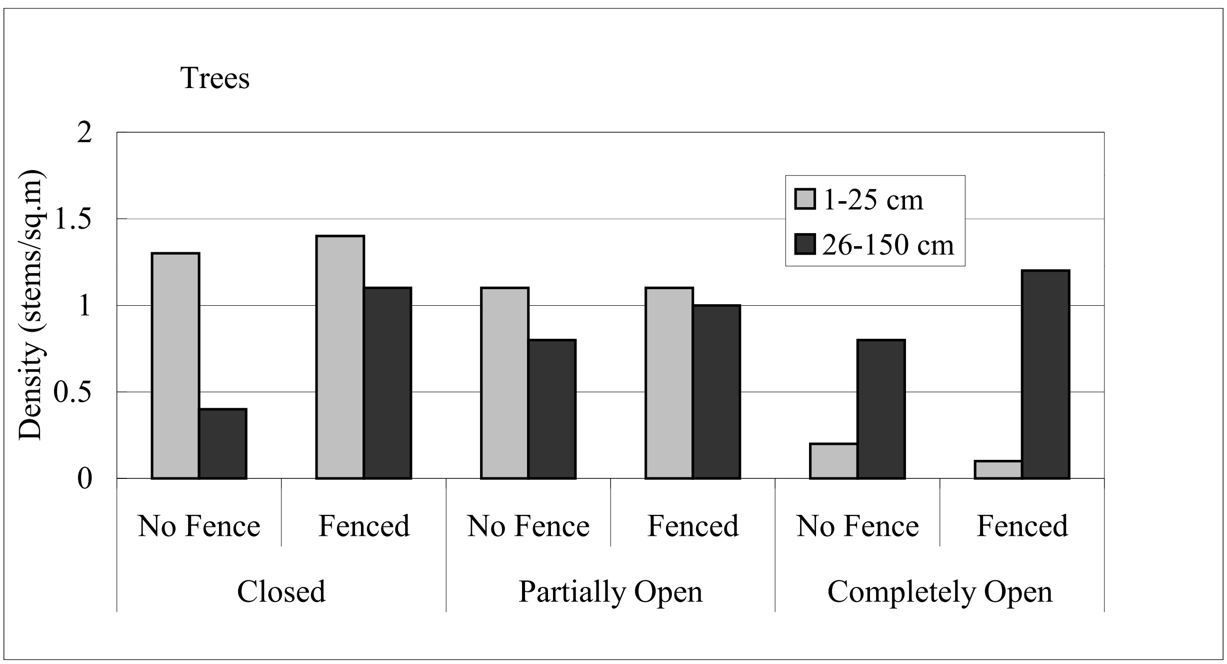


Figure 1. Average density of shrub and tree seedling-sized stems in the 1-25 and 26-150 cm height classes for no fence and fence treatments, by canopy treatment, at four-years-after treatment in 1993.

Table 18. Average[a] density of recruitment seedlings by species at the end of one, two, and four-years-after canopy treatment.

Species	One Year After	Two Years After	Four Years After
	(-------Density of seedlings per 1.0 square meter-------)		
Shrubs			
Amelanchier arborea	b	0.02	0.01
Cercis canadensis	0.21	0.31	0.10
Cornus florida	0.03	0.05	0.01
Lindera benzoin	0.14	0.19	0.14
Rubus spp.	b	0.01	0.01
Sassafras albidum	0.03	0.04	0.01
Viburnum prunifolium	0.03	0.01	0.01
Vitis spp.	1.66	1.49	0.43
Total Shrubs	2.10	2.13	0.71
Trees			
Acer rubrum	0.03	0.03	0.02
Betula lenta	b	0.01	b
Carya tomentosa	0.01	0.01	0.00
Fraxinus spp.	0.62	0.47	0.07
Liriodendron tulipifera	2.91	2.13	0.51
Nyssa sylvatica	0.03	0.02	b
Prunus avium	0.00	0.00	b
Prunus serotina	0.01	0.06	0.02
Quercus alba	0.01	0.01	0.00
Quercus rubra	0.02	0.02	0.01
Quercus velutina	b	0.01	0.00
Ulmus spp.	0.02	0.01	0.00
Total Trees	3.66	2.77	0.65

[a] Based on 216 - 2.0 m^2 plots
[b] No seedlings were inventoried.

By the fourth year after treatment, the total density of shrub recruitment seedlings had decreased to 0.71/m^2, and spicebush (*Lindera benzoin* (L.) Blume) had replaced redbud in terms of abundance. Total density of tree recruitment seedlings was 3.66, 2.77, and 0.65/m^2 in the first, second, and fourth years after treatment, respectively. At each inventory, yellow poplar and ash were the dominant species.

<u>Number of Shrub, Tree and Total Recruitment Species</u>

Analysis of variance indicated that woodlot and canopy treatment were consistently significant predictors of numbers of shrub, tree, and total recruitment species (Table 19). Fencing treatment had an effect on shrub species at one season after canopy treatments and on tree and total recruitment species at four-years-after treatments. Litter treatment was a consistently significant predictor for shrubs but not for trees or total recruitment species.

The lower numbers of shrub, tree, and total recruitment species at Herr Ridge were significantly different from Bushman Hill and Powers Hill at one, two, and four-years-after canopy treatments (Table 20). Initially, there were no significant differences between Bushman Hill and Powers Hill in the numbers of shrub or tree recruitment species, but by the fourth year after treatment, the greatest number of shrub, tree, and total recruitment species at Powers Hill was significantly different from Bushman Hill.

The lower numbers of shrub, tree, and total recruitment species in the closed canopy at each inventory were significantly different from partially and completely open canopy treatments (Table 21). In general, there were no significant differences in shrub and tree species recruitment numbers between the partially and completely open treatments over the first two-years-after treatment. By the fourth year after treatment, the greater number of tree recruitment species in the partially open treatment was significantly different from the completely open treatment.

At one-year-after treatments, the number of shrub recruitment species was greater in unfenced plots than in fenced plots (Table 22). However, there was no significant difference between unfenced and fenced plots in the number of shrub recruitment species by the second year after treatment. Fencing treatment had no significant effect on the number of tree or total recruitment species until the fourth year after treatment, at which time the greater numbers of tree and total recruitment species in the fenced plots were significantly different from the unfenced plots.

The greater number of shrub recruitment species for the litter-removed treatment than for the litter-retained treatment was significant for all inventories (Table 23). In contrast, the greater number of tree recruitment species for the litter-retained treatment was significantly different from the litter-removed treatment until the fourth growing season, at which time litter treatment no longer had a significant effect. Total number of recruitment species was significant for the litter treatment in the second and four-years-after treatment.

Table 19. Significant predictors (alpha = 0.05) of the average number of shrub, tree and total recruitment species and average density of recruitment seedlings at the end of one-, two- and four-years-after treatment.

Inventory Time - Factor	Degrees of Freedom	Shrub	Tree	Total
		(-------Predictor of number of species--------)		
One Year After				
Woodlot	2	Yes	Yes	Yes
Canopy	2	Yes	Yes	Yes
Fence	1	Yes	No	No
Litter	1	Yes	Yes	No
Two Years After				
Woodlot	2	Yes	Yes	Yes
Canopy	2	Yes	Yes	Yes
Fence	1	No	No	No
Litter	1	Yes	Yes	Yes
Four Years After				
Woodlot	2	Yes	Yes	Yes
Canopy	2	Yes	Yes	Yes
Fence	1	No	Yes	Yes
Litter	1	Yes	No	Yes
		(-------Predictor of density of seedlings------)		
One Year After				
Woodlot	2	Yes	Yes	Yes
Canopy	2	Yes	Yes	Yes
Fence	1	No	No	No
Litter	1	Yes	Yes	Yes
Two Years After				
Woodlot	2	Yes	Yes	Yes
Canopy	2	Yes	Yes	Yes
Fence	1	No	No	No
Litter	1	Yes	Yes	Yes
Four Years After				
Woodlot	2	Yes	Yes	Yes
Canopy	2	Yes	Yes	Yes
Fence	1	No	No	No
Litter	1	Yes	No	Yes

Table 20. Average[a] number of shrub, tree and total recruitment species and density of recruitment seedlings by woodlot at the end of one-, two- and four-years-after treatment.

Inventory Time - Woodlot	Shrub	Tree	Total
	(----Number of species per 2.0 square meters plot---)		
One Year After			
Bushman Hill	1.1b	1.1b	2.2b
Herr Ridge	0.3a	0.1a	0.4a
Powers Hill	1.4b	1.3b	2.8c
Two Seasons After			
Bushman Hill	1.1b	1.1b	2.2b
Herr Ridge	0.3a	0.2a	0.5a
Powers Hill	1.8c	1.2b	3.0c
Four Seasons After			
Bushman Hill	0.5b	0.4b	1.0b
Herr Ridge	0.1a	0.1a	0.3a
Powers Hill	1.4c	0.7c	2.1c
	(-----Density of seedlings per 1.0 square meter-----)		
One Year After			
Bushman Hill	2.1b	6.2b	8.3b
Herr Ridge	0.2a	0.1a	0.3a
Powers Hill	4.0c	4.7b	8.7b
Two Seasons After			
Bushman Hill	1.8b	4.7b	6.5b
Herr Ridge	0.2a	0.3a	0.5a
Powers Hill	4.6c	3.8b	8.4b
Four Seasons After			
Bushman Hill	0.4a	0.9b	1.3b
Herr Ridge	0.1a	0.1a	0.2a
Powers Hill	1.6b	1.0b	2.5c

[a] Based on 72 - 2.0 m^2 plots per woodlot. Values with the same letter within species groups by inventory time were not significantly different from each other at the 0.05 probability level.

Table 21. Average[a] number of shrub, tree and total recruitment species and density of recruitment seedlings by canopy treatment at the end of one-, two- and four-years-after treatment.

Inventory Time - Canopy Treatment	Shrub	Tree	Total
	(---Number of species per 2.0 square meters plot---)		
One Year After			
Closed Canopy	0.5a	0.4a	0.9a
Partially Open	1.2b	1.0b	2.2b
Completely Open	1.1b	1.1b	2.2b
Two Years After			
Closed Canopy	0.7a	0.5a	1.2a
Partially Open	1.3c	1.1b	2.4b
Completely Open	1.0b	1.0b	2.0b
Four Years After			
Closed Canopy	0.4a	0.2a	0.6a
Partially Open	0.8b	0.6c	1.5b
Completely Open	0.8b	0.4b	1.3b
	(-----Density of seedlings per 1.0 square meter------)		
One Year After			
Closed Canopy	0.5a	0.7a	1.2a
Partially Open	3.0b	4.4b	7.4b
Completely Open	2.9b	5.9b	8.7b
Two Years After			
Closed Canopy	0.8a	0.6a	1.4a
Partially Open	3.3b	3.7b	7.0b
Completely Open	2.5b	4.4b	6.9b
Four Years After			
Closed Canopy	0.3a	0.1a	0.4a
Partially Open	1.1b	0.9b	2.0b
Completely Open	0.7ab	0.9b	1.7b

[a] Based on 72 - 2.0 m^2 plots per canopy treatment. Values with the same letter within species groups and inventory time were not significantly different from each other at the 0.05 probability level.

Table 22. Average[a] number of shrub, tree and total recruitment species by fencing treatment at the end of one-, two- and four-years-after treatment.

Inventory Time - Fencing Treatment	Shrub	Tree	Total
	(----Number of species per 2.0 square meters plot---)		
<u>One Year After</u>			
No Fence	1.1b	0.8a	1.9a
Fence	0.8a	0.9a	1.7a
<u>Two Years After</u>			
No Fence	1.1a	0.8a	1.9a
Fence	1.0a	0.9a	1.9a
<u>Four Years After</u>			
No Fence	0.7a	0.3a	1.0a
Fence	0.7a	0.5b	1.2b

[a] Based on 108 - 2.0 m^2 plots per fencing treatment. Values with the same letter within species groups and inventory time were not significantly different from each other at the 0.05 probability level.

Table 23. Average[a] numbers of shrub, tree and total recruitment species and density of recruitment seedlings by litter treatment at the end of one-, two- and four-years-after treatment.

Inventory Time - Litter Treatment	Shrub	Tree	Total
	(---Number of species per 2.0 square meters plot---)		
One Year After			
Litter Retained	0.8a	1.0a	1.8a
Litter Removed	1.1b	0.7b	1.8a
Two Years After			
Litter Retained	0.8a	1.0b	1.8a
Litter Removed	1.3b	0.8a	2.0b
Four Years After			
Litter Retained	0.5a	0.4a	1.0a
Litter Removed	0.9b	0.4a	1.2b
	(-----Density of seedlings per 1.0 square meter-----)		
One Year After			
Litter Retained	0.9a	2.7a	3.5a
Litter Removed	3.3b	4.6b	8.0b
Two Years After			
Litter Retained	1.0b	2.1b	3.1b
Litter Removed	3.4a	3.8a	7.1a
Four Years After			
Litter Retained	0.4b	0.5a	0.9b
Litter Removed	1.0a	0.8a	1.8a

[a] Based on 108 - 2.0 m^2 plots per litter treatment. Values with the same letter with in species groups and inventory time were not significantly different from each other at the 0.05 probability level.

Densities of Shrub, Tree, and Total Recruitment Seedlings

Woodlot and canopy treatment were consistently significant predictors for densities of shrub, tree, and total recruitment seedlings (Table 19). Fencing treatment was not a significant predictor for any species group at any inventory. Litter treatment was a consistently significant predictor, with one exception: density of tree seedlings at the fourth year after treatment.

Powers Hill had the greatest density of shrub recruitment seedlings at each inventory (Table 20). Bushman Hill, over the first two-years-after treatment, had significantly greater densities of shrub recruitment seedlings than Herr Ridge; however, by the fourth year after there was no significant difference between the two woodlots. Herr Ridge had the lowest densities of tree and total recruitment seedlings at each inventory. At four-years-after treatments the only significant difference between Powers Hill and Bushman Hill was the greater density of total recruitment seedlings at Powers Hill.

In general, the lowest densities of shrub, tree, and total recruitment seedlings at each inventory in the closed canopy were significantly different from the partially- and completely-open-canopy treatments. There were no significant differences in the densities of shrub, tree, and total recruitment seedlings between the partially and completely open canopies (Table 21). The one exception was for the density of shrub recruitment seedlings at the fourth year after treatment, in which the completely open was not significantly different from the other two canopy treatments.

Fencing treatment was not a significant predictor of density of shrub, tree, or total recruitment seedlings at any inventory (Table 19); therefore, the best estimates of recruitment seedling densities are the grand means (Table 18).

At each inventory, the greater densities of shrub, tree, and total recruitment seedlings for the litter-removed treatment were significantly different from the litter-retained treatment, with one exception (Table 23). The one exception was that there was no significant effect of litter treatment on the density of tree recruitment seedlings at four-years-after canopy treatments.

Densities of Grape, Redbud, Ash, and Yellow poplar Recruitment Seedlings

Analysis of variance for individual species indicated that woodlot, canopy treatment, and litter treatment were consistently significant predictors of densities of grape, redbud, and yellow poplar recruitment seedlings (Table 24). Fencing treatment was not a significant predictor for any of the individual species' densities at any inventory.

The lowest recruitment seedling densities for all individual species at Herr Ridge were significantly different from those at either Bushman Hill or Powers Hill (Table 25). Bushman Hill frequently had equal-to-greater densities of ash and yellow poplar recruitment seedlings compared to Powers Hill; but the differences were significantly apparent in ash one- and two-years-after treatment (Table 25). Powers Hill frequently had greater densities of grape and redbud recruitment seedlings than Bushman Hill, with the difference being significant for all inventories except redbud one and four-years-after treatment (Table 25).

Table 24. Significant predictors (alpha = 0.05) of the average densities of grape, redbud, ash and yellow poplar recruitment seedlings at the end of one-, two- and four-years-after treatment.

Inventory Time - Factor	Degrees of Freedom	Grape	Redbud	Ash	Yellow poplar
		(---------Predictor of density of seedlings-----------)			
One Year After					
Woodlot	2	Yes	Yes	Yes	Yes
Canopy	2	Yes	Yes	Yes	Yes
Fence	1	No	No	No	No
Litter	1	Yes	Yes	Yes	Yes
Two Years After					
Woodlot	2	Yes	Yes	Yes	Yes
Canopy	2	Yes	Yes	No	Yes
Fence	1	No	No	No	No
Litter	1	Yes	Yes	No	Yes
Four Years After					
Woodlot	2	Yes	Yes	No	Yes
Canopy	2	Yes	Yes	Yes	Yes
Fence	1	No	No	No	No
Litter	1	Yes	Yes	No	Yes

Table 25. Average[a] densities of grape, redbud, ash and yellow poplar recruitment seedlings by woodlot at the end of one-, two- and four-years-after treatment.

Inventory Time - Woodlot	Grape	Redbud	Ash	Yellow poplar
	(---------Density of seedlings per 1.0 square meter---------------)			
<u>One Year After</u>				
Bushman Hill	1.6b	0.3b	1.2c	4.8b
Herr Ridge	0.2a	0.0a	0.0a	0.0a
Powers Hill	3.2c	0.3b	0.6b	3.9b
<u>Two Year After</u>				
Bushman Hill	1.3b	0.4b	0.9b	3.6b
Herr Ridge	0.1a	0.0a	0.0a	0.1a
Powers Hill	3.2c	0.6c	0.4b	3.3b
<u>Four Year After</u>				
Bushman Hill	0.3a	0.1ab	0.1a	0.8b
Herr Ridge	0.0a	0.0a	0.0a	0.0a
Powers Hill	1.0b	0.2b	0.1a	0.8b

[a] Based on 72 - 2.0 m^2 plots per woodlot. Values with the same letter within each species and inventory time were not significantly different from each other at the 0.05 probability level.

The closed canopy generally had the lowest seedling densities for all four species (Table 26). Grape, redbud and yellow poplar recruitment seedling densities in the closed canopy were significantly different from either the partially- or completely-open canopy treatments for all inventories, except redbud the fourth year after treatment (Table 26). Ash recruitment seedlings were always more abundant in the partially open canopy than in either the closed- or completely-open- canopy treatments with the differences being significant in the fourth year after treatment. There were no significant differences between the closed- or completely-open-canopy treatments in the densities of ash recruitment seedlings.

Fencing treatment had no significant effect on densities of recruitment seedlings at any inventory (Table 24); therefore, the individual species' mean values presented in Table 18 are the best estimates of recruitment seedling abundance.

At each inventory, the greater densities of grape, redbud, and yellow poplar recruitment seedlings for the litter-removed treatment were significantly greater than the litter-retained treatment (Table 27). Initially, the more abundant ash recruitment seedlings with litter-retained treatment was significantly different from the litter-removed treatment, but by the second growing season, there was no significant difference between the two litter treatments.

Artificial Oak Regeneration

Direct-seeded Seedlings

Of the 2,160 planted northern red oak acorns, 55% germinated. Of the 1,196 germinates, 86% were alive at the end of the second growing season. Woodlot and canopy treatment were significant predictors of direct-seeded seedling two-year mean survival. Powers Hill and Bushman Hill (Table 28) had significantly greater mean survival (87 and 86%, respectively) than Herr Ridge (74%). There was no significant difference in mean survival between Powers Hill and Bushman Hill. Two-year mean survival was lowest (74%) in the closed canopy, compared to 86 and 88% for partially-open and completely-open canopy treatments, respectively (Table 28). There was no significant difference in mean survival between partially-open and completely-open canopy treatments. There was no significant difference between fenced and unfenced seedling survival values, possibly due to limited foraging damage by the end of two growing seasons. For direct-seeded seedlings that survived to the end of the second growing season, white-tailed deer forage on only 19% of unfenced seedlings, whereas 10% of seedlings (fenced and unfenced) were clipped by small mammals (Table 29).

Significant predictors of direct-seeded seedling two-year mean height (20 cm) were woodlot, canopy treatment, and fencing treatment. Significant interactions were woodlot x canopy, canopy x fence, and woodlot x canopy x fence. Average height (Table 30) was greatest at Herr Ridge (25 cm). There was no significant difference in mean height between Bushman Hill and Powers Hill (19 and 17 cm, respectively). Two-year-old seedling mean height (Table 30) was

Table 26. Average[a] densities of grape, redbud, ash and yellow poplar recruitment seedlings by canopy treatment at the end of one-, two- and four-years-after treatment.

Inventory Time - Canopy Treatment	Grape	Redbud	Ash	Yellow poplar
	(-----------Density of seedlings per 1.0 square meter------------)			
One Year After				
Closed Canopy	0.2a	0.0a	0.3a	0.3a
Partially Open	2.4b	0.3b	1.0b	3.3b
Completely Open	2.3b	0.3b	0.5ab	5.2b
Two Years After				
Closed Canopy	0.3a	0.1a	0.3a	0.2a
Partially Open	2.3b	0.6b	0.6a	2.8b
Completely Open	2.1b	0.3a	0.4a	3.8b
Four Years After				
Closed Canopy	0.1a	0.0a	0.0a	0.0a
Partially Open	0.7b	0.2b	0.2b	0.7a
Completely Open	0.5b	0.1ab	0.0a	0.8b

[a] Based on 72 - 2.0 m^2 plots per canopy treatment. Values with the same letter within species and inventory time were not significantly different from each other at the 0.05 probability level.

Table 27. Average[a] densities of grape, redbud, ash and yellow poplar recruitment seedlings by litter treatment at the end of one-, two- and four-years-after treatment.

Inventory Time - Litter Treatment	Grape	Redbud	Ash	Yellow-poplar
	(------------Density of seedlings per 1.0 square meter------------)			
<u>One Year After</u>				
Litter Retained	0.5a	0.1a	0.8b	1.6a
Litter Removed	2.8b	0.3b	0.4a	4.2b
<u>Two Years After</u>				
Litter Retained	0.5a	0.1a	0.6a	1.2a
Litter Removed	2.6b	0.5b	0.3a	3.4b
<u>Four Years After</u>				
Litter Retained	0.2a	0.1a	0.1a	0.3a
Litter Removed	0.7b	0.2b	0.0a	0.7b

[a] Based on 108 - 2.0 m^2 plots per litter treatment. Values with the same letter within species and inventory time were not significantly different from each other at the 0.05 probability level.

Table 28. Average[a] percent survival two-years-after treatment for direct-seeded seedlings, planted seedlings, and planted saplings by woodlot and by canopy treatment.

Treatment	Direct-Seeded Seedlings	Planted Seedlings	Planted Saplings
	(-----------------------	% Survival	----------------------)
Woodlot			
Bushman Hill	86b	92a	81a
Herr Ridge	74a	93a	96b
Powers Hill	87b	93a	87ab
Canopy			
Closed	74a	91a	83a
Partially Open	86b	94a	92a
Completely Open	88b	93a	90a

[a] Values within the same source of regeneration and treatment with the same letter were not significantly different from each other at the 0.05 probability level.

Table 29. Average[a] frequency of white-tailed deer foraging and small mammal clipping in the second and fourth growing seasons by source of regeneration.

Time After Treatment	Direct-Seeded Seedlings	Planted Seedlings	Planted Saplings
	(-----------------------	% of Stems	----------------------)
Two Years			
Foraged	19	25	43
Clipped	10	25	1
Total	29	50	44
Two Years			
Foraged	32	29	46
Clipped	7	20	1
Total	39	49	47

[a] Foraging values were based on living stems on unfenced plots, and clipping values were based on all living stems, regardless of fencing.

Table 30. Average[a] height two-years-after treatment for direct-seeded seedlings, planted seedlings, and planted saplings by woodlot, canopy treatment and fence treatment.

Treatment	Direct-Seeded Seedlings	Planted Seedlings	Planted Saplings
	(-----------------------	(cm)	----------------------)
Woodlot			
Bushman Hill	19a	30a	157b
Herr Ridge	25b	43b	132a
Powers Hill	17ab	32a	145ab
Canopy			
Closed	11c	32a	134a
Partially Open	16a	32a	151a
Completely Open	30b	42b	146a
Fencing			
No Fence	15a	31a	142a
Fence	25b	39b	146a

[a] Values within the same source of regeneration with the same letter and treatment were not significantly different from each other at the 0.05 probability level.

significantly different among all canopy treatments (11, 16, and 30 cm for closed canopy, partially open, and completely open, respectively). Fenced seedlings averaged 25 cm in height, whereas unfenced seedling mean height was 15 cm (Table 30). The canopy x fence interaction (Table 31) indicated that mean height was greatest (37 cm) for the complete canopy opening where the seedlings were fenced. The next best two-year-old height was for the combined treatments of completely open canopy with no fence (21 cm) and partially open canopy with fence (20 cm). The worst combinations of treatments were closed canopy with fence (13 cm), partially open with no fence (12 cm), and closed canopy with no fence (10 cm).

Woodlot, canopy treatment, and fencing treatment were significant predictors of direct-seeded seedling four-year mean survival of 43%. Woodlot x canopy x fence was a significant interaction. Bushman Hill (Table 32) had significantly greater mean survival (56%) than Herr Ridge and Powers Hill (both 36%). Survival was highest (49%) in the partially-open canopy and was lowest (35%) in the closed canopy (Table 32). Survival in the completely-open canopy (44%) was not significantly different from the closed-canopy or the partially-open canopy treatment. Survival was higher (Table 32) for fenced seedlings (55%) than for unfenced seedlings (30%), possibly due to increased foraging damage by the end of four growing seasons. Overall, foraging damage increased from 29 to 39% for two- and four-year-old surviving direct-seeded seedlings, respectively (Table 29).

Four-years-after canopy treatment, significant predictors of direct-seeded seedling mean height (40 cm) were woodlot, canopy treatment, and fencing treatment. Significant interactions were woodlot x canopy, woodlot x fence, canopy x fence, and woodlot x canopy x fence. Average height (Table 33) was greatest at Herr Ridge (49 cm). There was no significant difference in mean height between Bushman Hill and Powers Hill (37 and 35 cm, respectively). Average height (Table 33) significantly increased with increasing amounts of canopy removed (20, 30, and 72 cm for closed, partially open, and completely open canopies, respectively). Fenced seedlings averaged 60 cm in height, whereas unfenced seedling mean height was 21 cm (Table 33). Four-year mean height was greatest (108 cm) in the completely open canopy with fencing (Table 34). Partially-open with fence (45 cm) and completely open with no fence (36 cm) were the next best combinations of treatments. Partially-open with no fence (15 cm) and closed canopy with no fence (13 cm) treatments had the lowest mean heights four-years-after canopy treatment.

Planted Seedlings

Planted seedling survival in the second growing season after canopy treatment averaged 93%, and there were no significant predictors of mean survival. Overall, 50% of the surviving planted seedlings were foraged on by deer or clipped by small mammals by the end of two growing seasons (Table 29), demonstrating a high number of planted seedlings initially could withstand foraging damage.

Overall mean height of the planted seedlings was 35 cm in the second growing season after canopy treatment. Significant predictors of planted seedling two-year mean height were woodlot,

Table 31. Average[a] height two-years-after canopy treatment of direct-seeded seedlings, planted seedlings, and planted saplings by canopy and fencing treatment.

Canopy Treatment	Fence Treatment	Direct-Seeded Seedlings	Planted Seedlings	Planted Saplings
		(---------------------	cm	---------------------)
Closed	No Fence	10a	28a	122a
Closed	Fenced	13a	35bc	147ab
Partially Open	No Fence	12a	29ab	164c
Partially Open	Fenced	20b	35bc	137ab
Completely Open	No Fence	21b	37c	138ab
Completely Open	Fenced	37c	46d	154c

[a] Values within the same source of regeneration with the same letter were not significantly different from each other at the 0.05 probability level.

Table 32. Average[a] survival four-years-after treatment for direct-seeded seedlings, planted seedlings, and planted saplings by woodlot, canopy treatment and fence treatment.

Treatment	Direct-Seeded Seedlings	Planted Seedlings	Planted Saplings
	(-----------------------	(% Survival)	----------------------)
Woodlot			
Bushman Hill	56b	73b	52a
Herr Ridge	36a	56a	55a
Powers Hill	36a	45a	46a
Canopy			
Closed	35a	52a	38a
Partially Open	49b	67a	63b
Completely Open	44ab	56a	52ab
Fencing			
No Fence	30a	40a	47a
Fence	55b	76b	55a

[a] Values within the same source of regeneration and treatment with the same letter were not significantly different from each other at the 0.05 probability level.

Table 33. Average[a] height four-years-after treatment for direct-seeded seedlings, planted seedlings, and planted saplings by woodlot canopy and by fence treatment.

Treatment	Direct-Seeded Seedlings	Planted Seedlings	Planted Saplings
	(-----------------------	(% Survival)	----------------------)
Woodlot			
Bushman Hill	37a	39a	130a
Herr Ridge	49b	59b	160a
Powers Hill	35a	46a	147a
Canopy			
Closed	20a	28a	105a
Partially Open	30b	43b	159b
Completely Open	72c	73c	172b
Fencing			
No Fence	21a	29ab	133a
Fence	60b	67b	158b

[a] Values within the same source of regeneration and treatment with the same letter were not significantly different from each other at the 0.05 probability level.

Table 34. Average[a] height four-years-after treatment for direct-seeded seedlings, planted seedlings, and planted saplings by canopy and fencing treatment.

Canopy Treatment	Fence Treatment	Direct-Seeded Seedlings	Planted Seedlings	Planted Saplings
		(----------------------	cm ----------------------	)
Closed	No Fence	13a	20a	84a
Closed	Fenced	26ab	36a	126a
Partially Open	No Fence	15a	29a	150a
Partially Open	Fenced	45b	58b	168a
Completely Open	No Fence	36b	37a	164a
Completely Open	Fenced	108b	108c	180a

[a] Values within the same source of regeneration with the same letter were not significantly different from each other at the 0.05 probability level.

canopy treatment, and fencing treatment. Significant interactions were woodlot x canopy, canopy x fence, and woodlot x canopy x fence. Average height (Table 30) at Herr Ridge (43 cm) was significantly different from that found at Powers Hill (32 cm) and Bushman Hill (30 cm). There was no significant difference in mean height between Powers Hill and Bushman Hill. Average height (Table 30) in the completely-open-canopy treatment (42 cm) was significantly different that in the closed- or partially-open-canopy treatments (both 32 cm). Planted seedling mean height was 31 cm for unfenced seedlings, which was significantly different from the 39 cm for fenced seedlings (Table 30). The greatest two-year mean height (Table 31) was in the completely open canopy with fencing (46 cm). The next best mean height values that were not significantly different from one another were the combination treatments of completely open with no fence (37 cm), partially open with fence (35 cm), and closed canopy with fence (35 cm). Plots with partially-open canopy with no fence (29 cm) and closed canopy with no fence (28 cm) had the lowest mean height two-years-after canopy treatment.

Overall mean survival of the planted seedlings was 58% in the fourth growing season after canopy treatment. Significant predictors of the four-year-old planted seedling mean survival were woodlot and fencing treatment. Woodlot x fence was a significant interaction. Bushman Hill had the highest survival (73%), compared to 56 and 45% survival at Herr Ridge and Powers Hill, respectively (Table 32). Frequency of browsing and clipping of planted seedlings remained at about 50% (Table 29) at the end of four growing seasons, yet four-year survival was significantly higher (Table 32) for fenced seedlings (76%) than for unfenced seedlings (40%). These results suggested greater prolonged or repeated foraging damage for unfenced stems than for fenced stems, thus reducing unfenced seedling survival.

Overall mean height of the planted seedlings was 48 cm in the fourth growing season after canopy treatment. Significant predictors of planted seedling four-year mean height were woodlot, canopy treatment, and fencing treatment. Significant interactions were woodlot x canopy and canopy x fence. Average height (Table 33) was greatest at Herr Ridge (59 cm). There was no significant difference in mean height between Powers Hill (46 cm) and Bushman Hill (39 cm). Increasing the amount of canopy that was removed significantly increased the height of the four-year-old seedlings (Table 33). Average height values were 28, 43, and 73 cm for the closed, partially open, and completely open canopy treatments, respectively. All of the canopy treatment means were significantly different from one another. Fencing significantly increased seedling height: 67 cm for fenced stems and 29 cm for unfenced stems (Table 33). Average height was greatest (108 cm) in the completely open canopy with fencing (Table 34). The partially open canopy with fence had the second greatest mean height (58 cm). Lowest mean height values were in the completely-open canopy with no fence (37 cm), closed canopy with fence (36 cm), partially-open canopy with no fence (29 cm), and closed canopy with no fence (20 cm).

Planted Saplings

Overall mean survival of the planted saplings was 88% in the second growing season after canopy treatment. Woodlot was the only significant predictor of planted sapling mean survival two-years-after canopy treatment. Average survival (Table 28) at Herr Ridge (96%) was significantly different from the mean survival rate at Bushman Hill (81%). Average survival at

Powers Hill (87%) was not significantly different from rates at Herr Ridge or Bushman Hill. Planted saplings demonstrated a high capacity to withstand browsing and clipping over the first two growing seasons, with 44% of surviving stems damaged (Table 29).

Overall mean sapling height two-years-after canopy treatment was 144 cm. Woodlot was a significant predictor of two-year mean height. Significant interactions were canopy x fence and woodlot x canopy x fence. Average height (Table 30) at Bushman Hill (157 cm) was significantly different from the mean height at Herr Ridge (132 cm). Average height at Powers Hill (145 cm) was not significantly different from Bushman Hill or Herr Ridge. The canopy x fence interaction (Table 31) indicated that mean height was significantly affected only for the closed canopy with no fencing treatment combination.

Overall mean survival of the planted saplings was 51% in the fourth growing season after canopy treatment. Canopy treatment was the only significant predictor of planted sapling mean survival four-years-after canopy treatment. Survival was highest (63%) in the partially open canopy and was lowest (38%) in the closed canopy (Table 32). Survival in the completely open canopy plots (52%) was not significantly different from that in the other two canopy levels. Overall, frequency of foraging increased slightly to 47% (Table 29) by the end of the fourth growing season, yet there was no significant difference in four-year survival rates between fenced and unfenced stems. These results suggested a high capacity for the saplings to withstand prolonged foraging damage.

Overall mean sapling height four-years-after canopy treatment was 145 cm. Canopy treatment and fencing treatment were significant predictors of planted sapling four-year mean height. Average sapling height for the completely open (172 cm) and partially open (159 cm) canopy treatments (Table 33) were significantly different from the closed canopy treatment (105 cm). There was no significant difference in height between the completely and partially open canopy treatments. Average height (Table 33) for fenced saplings (158 cm) was significantly different from unfenced saplings (133 cm).

Discussion

Existing Herbaceous and Woody Plants

Woodlot, canopy and fence treatments had significant effects on the coverage of herbaceous plants, the number of herbaceous species, and the number of species and density of shrub and tree seedling-sized stems. The woodlots were selected to represent the range of conditions that the resources managers would need to account for when developing a park woodlot management program. Woodlot consistently influenced the average density of before and after treatment seedling-sized stems. Before treatment average densities of shrub and tree (total) seedling-sized stems were 12.5, 6.8 and 9.8/m^2 for Bushman Hill, Herr Ridge and Powers Hill woodlots, respectively. In the second growing season after treatment, average densities of total seedling-sized stems for Bushman Hill, Herr Ridge and Powers Hill increased to 16.5, 6.3 and 15.3/m^2, respectively. Average four-years-after treatment densities of total seedling-sized stems for Bushman Hill, Herr Ridge and Powers Hill declined to 9.3, 5.7 and 9.5/m^2, respectively. Although woodlot was frequently a significant variable in the understory responses, we consider this to represent the range of responses to be expected rather some unique woodlot-specific conditions that would alter the development of a park woodlot management program. The study has uncovered a number of responses to canopy and fence treatments that should have park-wide application in the development of a woodlot management program.

There were three replications of each canopy treatment in each woodlot. Assignment of closed- and partially-open canopy treatments was at random. Assignment of the completely-open canopy treatment was to locations that had openings in the canopy that were created by recent mortality. These natural openings were expanded to meet the 0.02 ha requirement. Analyses of the pre-treatment herbaceous and woody plants indicated that there were no significant effects among canopy treatments, except for total herbaceous coverage. Assignment of fence was at random and there was no significant fence effect on the pre-treatment herbaceous and woody plants except for density of seedling-sized shrub stems. Based on these evaluations we believe the responses to the canopy and fence treatments in these three woodlots were unbiased by any pre-treatment conditions.

Study treatments were conducted in the 1992-93 dormant season. The March-April white-tailed deer densities in a 2,862 ha sample area containing the woodlots were 1,337 (1992), 1,500 (1993), 1,035 (1994) and 1,059 (1995) (Frost et al. 1997). A herd reduction program was started in the fall of 1995. This program reduced the herd density to 500 in March-April 1996 (Frost et al. 1997). Based on our field observations of foraging and animal sightings in the study woodlots, we do not believe the herd reduction program influenced the four-years-after treatment fence treatment data.

Pre-treatment inventories indicated that the natural processes were in place to establish and maintain a desirable mixture of herbaceous, shrub and tree species in the understory of the woodlots. There were at least 40 herbaceous, 12 shrub and 13 tree species inventoried on the 162 2.0 m^2 plots. Pre-treatment inventories indicated a good variety of herbaceous plants occupying an average of 22 to 37% of the soil surface, and woody plants with an average of 5.4 to 5.8/m^2 shrub and 1.3 to 6.5/m^2 tree seedling-sized stems.

The herbaceous plants responded quickly to the reduction in overstory canopy. In the first growing season after treatment, total herbaceous coverage in the partially open canopy treatment areas was 52% greater than the pre-treatment value, and 29% greater than the first-year-after treatment closed canopy value. First year after treatment total herbaceous coverage in the completely open canopy was 103% greater than the pre-treatment value, and 97% greater than the first year after treatment closed canopy value. The partially open and completely open canopy grass coverage values continued to increase through all inventories. The partially open canopy forb, vine and total herbaceous coverage values reached a maximum at two-years-after treatment whereas the completely open canopy forb and total herbaceous coverage values were maximum in the first year after treatment.

Fence was not a consistent significant factor in the coverage of the herbaceous plants among the inventories. This result was likely due to the history of white-tailed deer foraging preferences. Bedstraw, enchanter's nightshade, Virginia creeper, white snakeroot and wild white licorice were consistently the most widely distributed and abundant plants among all inventories, and these plants were low in white-tailed deer food preference. In addition, the white-tailed deer foraged very little, if at all, on white grass which became a dominant ground cover at Powers Hill.

The response of this herbaceous community to the canopy treatments can be very important to the successful establishment of new shrub and tree seedlings, and the growth of existing shrub and tree seedling-sized stems. Herbaceous communities that have >50% coverage of the ground may affect the germination or growth of desirable shrub and tree seedlings by modifying the seedbed conditions, reducing the availability of sunlight and nutrients, or simply being physical barriers. These impediments to the establishment of desirable shrub and tree seedlings can be particularly acute when the plants are invasive and non-native, such as white grass.

The responses of shrub and tree seedling-sized stems to treatments were less dramatic than that of the herbaceous plants. Overall density values of shrub seedling-sized stems were not influenced by either canopy or fence treatments, except four-years-after treatment. Overall density values of tree seedling-sized stems were influenced by the canopy treatments at two and four-years-after treatment, and by fence treatments four-years-after treatment. When the densities of shrub and tree seedling-sized stems by height class were evaluated, both canopy and fence were important determinants two and four-years-after treatment. In general, the more open the overstory canopy in the presence of fence, the greater the density of shrub and tree seedling-sized stems in the taller height classes.

Although there were abundant shrub and tree seedling-sized stems of a wide variety of species in the pre-treatment inventories, they were mainly in the 1-25 cm height class. Continuation of a tree-dominated community in these woodlots requires that these seedling-sized stems grow into the next size class. In the pre-treatment inventory, there were only 0.3 tree species stems/m^2 in the 26-150 cm height class and 0.1 tree species stems/m^2 in the >50 cm height class. If all of these >50 cm height class tree stems would grow to the small sapling-size class (0.1 to 1.9 cm in diameter) there would be about 1,000 stems/ha. This is only 22% of the density needed to continue the forested condition (Storm et al 1995).

Reducing the white-tailed deer herd is essential to increasing the height and vigor of shrub and tree seedling-sized stems. Without reduced foraging by white-tailed deer, few of the desirable tree species will have the opportunity to grow into the sapling-size class. As compared to no fence, having fence in the closed canopy increased the four-years-after treatment density of 51-150 cm height-class-seedling-sized stems for shrubs from $1.0/m^2$ to $1.7/m^2$ and for trees from $0.1/m^2$ to $0.4 / m^2$. Having a fence in the partially-open canopy resulted in increases of $1.6/m^2$ to $3.5/m^2$ for shrubs and $0.2/m^2$ to $0.4/m^2$ for trees. Having a fence in the completely-open canopy resulted in increases of $3.1/m^2$ to $5.1/m^2$ for shrubs and $0.6/m^2$ to $1.1/m^2$ for trees.

Treatments had little effect on the species composition on the 2.0 m^2 herbaceous and woody plant inventory plots. This result was mainly due to the manner in which the canopy treatments were conducted with expressed intention to minimize disturbance to the existing soil and plant conditions. It is particularly important to note that none of the treatments increased the oak component in the woodlots. There can be a number of natural factors controlling the successful establishment and growth of oak in these woodlots but canopy levels and white-tailed deer density did not appear to be among them.

Recruitment of Shrubs and Trees

We found woodlot conditions favorable for germination of seeds for eight shrub and 12 tree species. The density of 2.10 shrub recruitment seedlings/m^2 and 3.7 tree recruitment seedlings/m^2 in the first-year-after treatment indicated overall germination and establishment potential was sufficient to maintain a forest community. Densities of hickory and oak recruitment seedlings was disappointing, and apparently not related to woodlot, canopy openings, white-tailed deer or litter conditions. Most likely reasons for the lack of hickory and oak recruitment seedlings were insufficient seed production, undesirable seed storage conditions, or seed predation by animals, birds or insects.

There were greater numbers of tree-recruitment species than shrub-recruitment species at the end of one, two, and four growing seasons after canopy treatments. Species numbers increased for both trees and shrubs over the first two growing seasons, but tree species were declining by the end of the fourth growing season. Densities of tree seedlings were greater than densities of shrub seedlings for the first two inventories. However, by the fourth growing season, seedling densities dramatically decreased for both species groups, with shrubs slightly more abundant than trees. Densities of recruitment seedlings for the most abundant individual species also decreased over time. By the end of the fourth growing season, the order of species in terms of abundance was yellow poplar, grape, redbud, and ash.

Results indicated a rapid initial increase in germinants in response to openings in canopy, with poor survival in partially- and completely-open canopy treatments, by the end of the fourth growing season. Indeed, in general (1) numbers of shrub, tree, and total species and density of recruitment seedlings were lower in closed canopy than in partially- and completely-open canopy and (2) in closed canopy greater percentages of shrub and total recruitment seedlings survived from the initial inventory to the end of the fourth growing season. For individual species, greater percentages of grape and redbud survived in closed canopy, and survival was highest for ash and yellow poplar in partially-open canopy. Overall, partially-open canopy produced slightly better results than completely-open canopy and is the recommended treatment for the three woodlots.

By the end of four growing seasons, Herr Ridge had from 5 to 14 times fewer recruitment seedlings of shrub species and from 4 to 7 times fewer tree recruitment seedling species than the other woodlots. In terms of densities of recruitment seedlings, Herr Ridge had from 4 to 16 times fewer shrubs and from 9 to 10 times fewer trees than the other woodlots. Further, densities of grape, redbud, ash, and yellow poplar recruitment seedlings were lowest at Herr Ridge. Although Park-wide recommendations can be made, natural regeneration at Herr Ridge may fail regardless of management practices.

Artificial Oak Regeneration

Two-years-after canopy treatment survival was high for direct-seeded seedlings, planted seedlings, and planted saplings (86, 93, and 88%, respectively). Bowersox and McCormick (1987) also reported 93% survival for planted northern red oak seedlings after two growing seasons. Zaczek et al. (1991) found oak seedling survival to be highly variable (48 to 97%) three years after planting. Two-year survival and growth of artificial northern red oak regeneration was consistently affected by woodlot, mainly because the three woodlots were selected as representative of the range of conditions throughout the park. Although survival of direct-seeded seedlings was lowest at Herr Ridge, height was greatest for both direct-seeded seedlings and planted seedlings at this woodlot. This result indicated a difficulty in initially establishing seedlings at Herr Ridge, but once established, seedlings grew well. For planted saplings, height growth was greatest at Bushman Hill, but initial survival was lowest at this woodlot. Two-year survival of direct-seeded seedlings increased with increasing light levels. Sander (1990) concluded light levels in closed stands are often too low for oak seedlings to survive. Partially-open or completely open canopy is recommended to improve direct-seeded seedling two-year survival. Butterworth and Tzilkowski (1990) found no significant effect of fencing treatment on the number of surviving northern red oak seedlings after one growing season. Fencing treatment had no significant effect on two-year survival of direct-seeded seedlings, planted seedlings, or planted saplings. Foraging damage may have been limited for the smaller-sized direct-seeded seedlings; the larger planted seedlings and saplings may have been able to withstand greater initial browsing and clipping.

Two-year height growth of direct-seeded and planted seedlings increased with increasing light levels and with fencing - consistent with the use of even-aged silviculture (Hannah 1987, Loftis 1990, Ward 1992) and fencing (George et al. 1991) to reproduce northern red oak. The completely open canopy with fencing is recommended to maximize two-year height for both sources of regeneration. Saplings grew equally well over the first two growing seasons using any combination of canopy level and fencing level, except closed canopy and no fencing. Partially-open canopy and no fencing or closed canopy and fencing is recommended to achieve greatest height at lowest cost.

Four-years-after canopy treatment survival was moderate for direct-seeded seedlings, planted seedlings, and planted saplings (43, 58, and 51%, respectively). These results are comparable to the 33 to 50% of planted northern red oak seedlings expected to be alive five years after planting (Johnson et al. 1986). Again, woodlot consistently affected the survival and growth of artificial northern red oak regeneration, except for saplings. Herr Ridge and Powers Hill had lowest four-year survival for direct-seeded seedlings and planted seedlings. Nevertheless, Herr Ridge had greatest mean height values for both sources of regeneration, further supporting the problem of poor seedling establishment, but best growth, at the Herr Ridge woodlot. By the end of the fourth growing season, Bushman Hill no longer had lowest sapling survival and greatest sapling height of the three woodlots. Since the three woodlots represented park-wide conditions, bare-root saplings may be planted throughout the park with survival and growth expected to be similar among woodlots by the end of four growing seasons. Direct-seeded and planted seedling four-year survival was lower on unfenced plots than on fenced plots - consistent with the findings by Teclaw and Isebrands (1991), in which prolonged foraging damage resulted in northern red oak regeneration failure. Thus, fencing is recommended to maximize four-year survival for both sources of regeneration. Fencing had no significant effect on four-year survival of planted saplings, possibly indicating that saplings had a greater capacity for withstanding prolonged foraging damage than seedlings. For saplings, partially or completely open canopy is recommended to maximize four-year survival.

Four-year height of direct-seeded seedlings, planted seedlings, and planted saplings increased with increasing light levels and with fencing. For direct-seeded seedlings and planted seedlings, the completely open canopy with fencing is recommended for greatest four-year height. Since the canopy x fence interaction was not significant for planted sapling four-year height, it was unnecessary to use both increased direct sunlight and fencing to increase height. Thus, the partially or completely open canopy is recommended to maximize the height of four year old planted saplings.

Finally, survival was moderate four years after planting, and thus all three sources of reproduction, have potential for artificially regenerating the woodlots. However, saplings did not grow at acceptable rates. Average sapling height was 144 and 145 cm at two and four years after planting, respectively. At the end of four growing seasons, both direct-seeded and planted seedlings had a maximum height of 108 cm when protected from deer and exposed to full sunlight. From these results, the greater overall height of saplings may have been offset by the greater costs and efforts of production and of planting saplings. The use of direct seeding may reduce costs and direct-seeded and planted seedlings were similar in size (consistent with the findings by Zaczek et al. 1991). Therefore, direct-seeded seedlings are the recommended source of northern red oak to artificially regenerate woodlots.

Conclusions

We conclude that any efforts to renew the woodlots in the park should include efforts to reduce the foraging by white-tailed deer. Based on the herbaceous and woody plant responses to the canopy treatments, we conclude that invasive, non-native plant species should be removed from the woodlots before there is any attempt to start the renewal process. In areas of a woodlot, which are lacking sufficient desirable shrub and tree seedling-sized stems, we recommend conducting seedbed cultural practices to stimulate the germination and growth of additional seedlings in closed or partially-open canopy conditions. In woodlots that have sufficient numbers of desirable shrub and tree seedling-sized stems, but mostly <26 cm in height or of low vigor, we conclude that partial canopy openings will be needed to increase stem size and vigor. These practices should permit the desirable shrub and tree seedling-sized stems to become stronger competitors with the herbaceous community. In areas of a woodlot that have sufficient numbers of desirable shrub and tree seedling-sized stems that are mostly >25 cm in height or of high vigor, we conclude that either partial or complete canopy openings (up to 0.20 ha) will be the optimum treatment.

Fencing treatment had no significant effect on recruitment of shrub or tree seedlings. Therefore, fencing woodlots is not expected to improve the number of species or the density of the seedlings that germinate. However, use of fencing to reduce white-tailed deer foraging did increase the number of tree species by four years after treatment. Therefore, programs to reduce by white-tailed deer foraging are recommended.

The litter-retained treatment initially increased the densities of ash and all tree species combined recruitment seedlings, however by the fourth growing season, litter treatment had no significant effect on the density of ash and all tree species combined recruitment seedlings. A litter-removed treatment is recommended to increase numbers of shrub species, densities of shrub combined species recruitment seedlings, and densities of grape, redbud, and yellow poplar recruitment seedlings by the fourth growing season.

We found that overstory tree competition and foraging by large and small mammals had major impacts on the survival and growth of artificial northern red oak regeneration. By the end of four growing seasons, opening the canopy or using fencing was best for survival and growth of direct-seeded seedlings, planted seedlings, and planted saplings. For planted saplings, both four-year survival and height were maximized in the partially- or completely-open canopy treatment. For direct-seeded seedlings and planted seedlings, fencing improved four-year survival. Four-year height was significantly increased for both sources of regeneration when fencing was used in conjunction with the completely-open canopy. Finally, all three sources of northern red oak had the potential to artificially regenerate mixed-oak woodlots. We used individual acorn protectors and still encountered frequent pilferage by very aggressive gray squirrels. If acorns pilferage by small mammals can be reduced, direct-seeded seedlings would be an excellent practice to add northern red oak to the understory of the mixed-oak woodlots. Both planted seedlings and saplings offer good promise of adding northern red oak to the woodlots but height growth was below expectations.

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Appendix A. Common and scientific names of herbaceous (forbs and grasses), shrub, tree and vine species identified during the study and presented in this report.

Common and scientific names of herbaceous (forbs and grasses), shrub, tree and vine species identified during the study and presented in this report. Herbaceous species include annual, biennial, or perennial plants whose exposed parts die down at the end of growing season and included forbs (F) and grasses or grass-like (G); a shrub (S) is defined as having a persistent woody stem, may have either single or multiple stems and are <10 m in height; a tree (T) is defined as having a persistent woody stem, usually a single stem and capable of achieving heights >10 m; and a vine (V) is defined as having a persistent woody stem that is capable of climbing. All species in this appendix are listed by family, scientific name, and common name where known. Taxonomy follows that of Pool (1978) and Rhoads and Klein (1993).

Aceraceae	*Acer rubrum* L. - red maple (T) *Acer saccharum* Marshall - sugar maple (T)
Anacardiaceae	*Toxicodendron radicans* (L.) Kuntze - poison-ivy (V)
Apiace	*Sanicula marilandica* L. black snakeroot
Apocynaceae	*Apocynum spp.* - dogbane species (F)
Araceae	*Arisaema triphyllum* (L.) Schott - jack-in-the-pulpit (F)
Aristolochiaceae	*Aristolochia sepentaria* - Virginia snakeroot (F)
Asteraceae	*Bidens vulgata* Greene - beggar-ticks (F) *Cirsium spp.* - thistle species (F) *Erechtites hieraciifolia* (L.) Raf. ex DC. - pilewort (F) *Eupatorium rugosum* Houtt - white-snakeroot (F) *Solidago spp.* - goldenrod species (F) *Taraxacum spp.* - dandelion species (F)
Balsaminaceae	*Impatiens capensis* Meerb. - spotted touch-me-not (F)
Berberidaceae	*Berberis thunbergii* DC. - Japanese barberry (S)
Boraginaceae	*Borago* spp. Borage species (F) *Cynoglossum virginianum* L. - wild comfrey (F)
Caesalpiniaceae	*Cercis canadensis* L. - redbud (S)
Caprifoliaceae	*Lonicera japonica* Thunb. - Japanese honeysuckle (V) *Viburnum prunifolium* L. - black-haw (S)

Appendix A. Common and scientific names of herbaceous (forbs and grasses), shrub, tree and vine species identified during the study and presented in this report (continued).

Clusiaceae	*Hypericum perforatum* L. - St.-John's-wort (F)
Cornaceae	*Cornus florida* L. - flowering dogwood (S)
Cupressaceae	*Juniperus virginiana* L. eastern red-ceder (T)
Cyperaceae	*Carex* species - sedge species (G)
Euphorbiaceae	*Acalypha rhomboidea* Raf. - three-seeded mercury (F)
Fabaceae	*Agrimonia striata* L. - yellow agrimony (F) *Amphicarpaea bracteata* (L.) Fern. - hog-peanut (V) *Desmodium nudiflorum* (L.) DC. - naked-flowered tick-trefoil (F) *Desmodium paniculatum* (L.) DC. - panicled tick-trefoil (F) *Desmodium perplexium DC* - Dillan's tick-trefoil (F) *Lactuca canadensis* L. - wild lettice (F) *Robinia pseudoacacia* L. - black locust (T)
Fagaceae	*Quercus alba* L. - white oak (T) *Quercus rubra* L. - northern red oak (T) *Quercus velutina* Lam. - black oak (T)
Geraniaceae	*Geranium maculatum* L. - wild geranium (F)
Hamamelidaceae	*Hamamelis virginiana* L. - witch-hazel (T)
Juglandaceae	*Carya glabra* (P. Mill.) Sweet - pignut hickory (T) *Carya tomentosa* (Lam. ex Poir.) Nutt. - mockernut hickory (T)
Lamiaceae	*Collinsonia canadensis* L. - horse-balm (F) *Scutellaria spp.* - skullcap species (F)
Lauraceae	*Lindera benzoin* (L.) Blume - spicebush (S) *Sassafras albidum* (Nutt.) Nees - sassafras (S)
Liliaceae	*Smilacina racemosa* (L.) Desf. - false solomon's-seal (F) *Uvularia perfoliata* L. - bellwort (F)
Magnoliaceae	*Liriodendron tulipifera* L. - yellow poplar (T)
Nyssaceae	*Nyssa sylvatica* Marshall - black-gum (T)

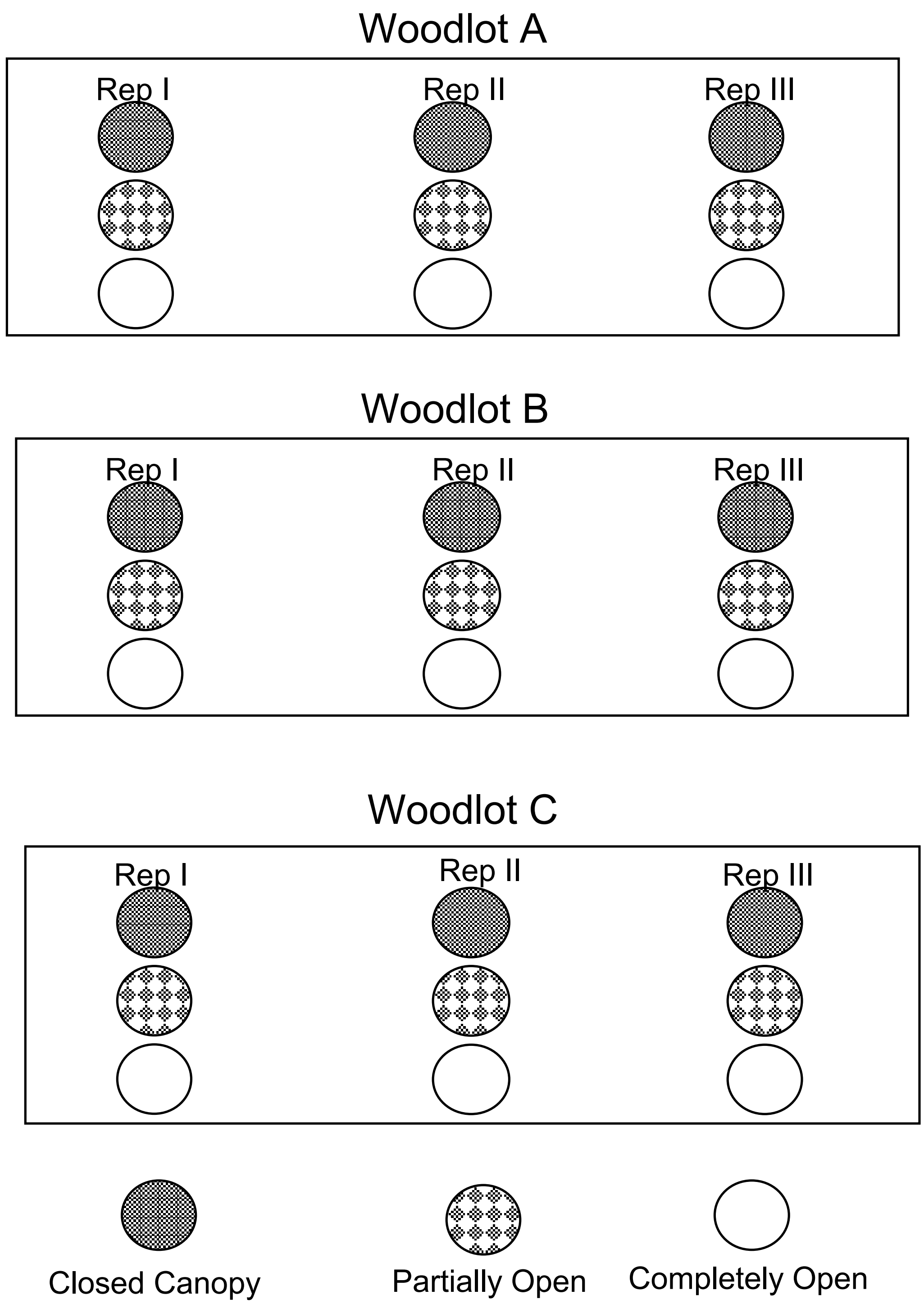
Appendix A. Common and scientific names of herbaceous (forbs and grasses), shrub, tree and vine species identified during the study and presented in this report (continued).

Oleaceae	*Fraxinus spp.*- ash spp. (T)
Onagraceae	*Circaea lutetiana* L. - enchanter's-nightshade (F)
Orchidaceae	*Galearis spectabilis* (L.) Raf. - showy orchid (F)
Oxalidaceae	*Oxalis stricta* L. - yellow wood-sorrel (F)
Phytolaccaceae	*Phytolacca americana* L. - pokeweed (F)
Plantaginaceae	*Plantago major* L. - common plantain (F)
Poaceae	*Elymus hystrix* L. - bottlebrush grass (G) *Leersia virginica* Willd. - white grass (G) *Panicum boscii* Poir. - panic-grass (G) *Poa spp.* - grass species (G)
Polygonaceae	*Polygonum hydropiper* L. - long-bristled smartweed (F) *Polygonum persicaria* L. - lady's-thumb (F) *Polygonum virginianum* L. - jumpseed (F)
Ranunculaceae	*Hepatica nobilis* P. Mill. - round-lobed hepatica (F) *Ranunculus* species - buttercup species (F) *Thalictrum thalictroides* (L.) Eames & B. Boivin - rue-anemone (F)
Rosaceae	*Amelanchier arborea* (Michx.f.) Fern. - serviceberry (S) *Geum canadense* Jacq. - white avens (F) *Potentilla canadensis* L. - dwarf cinquefoil (F) *Prunus avium* (L.) L. - sweet cherry (T) *Prunus serotina* Ehrh. - wild black cherry (T) *Rosa spp.* - mainly multiflora rose (S) *Rubus spp.* - blackberry, dewberry or black raspberry (S)
Rubiaceae	*Galium circaezans* Michx. - wild licorice (F) *Galium concinnum* Torr. & A. Gray - bedstraw (F)
Ulmaceae	*Ulmus spp.* - elm species (T)
Urticaceae	*Pilea pumila* (L.) A. Gray. - clearweed (F)
Verbenaceae	*Verbena urticifolia* L. - white vervain (F)

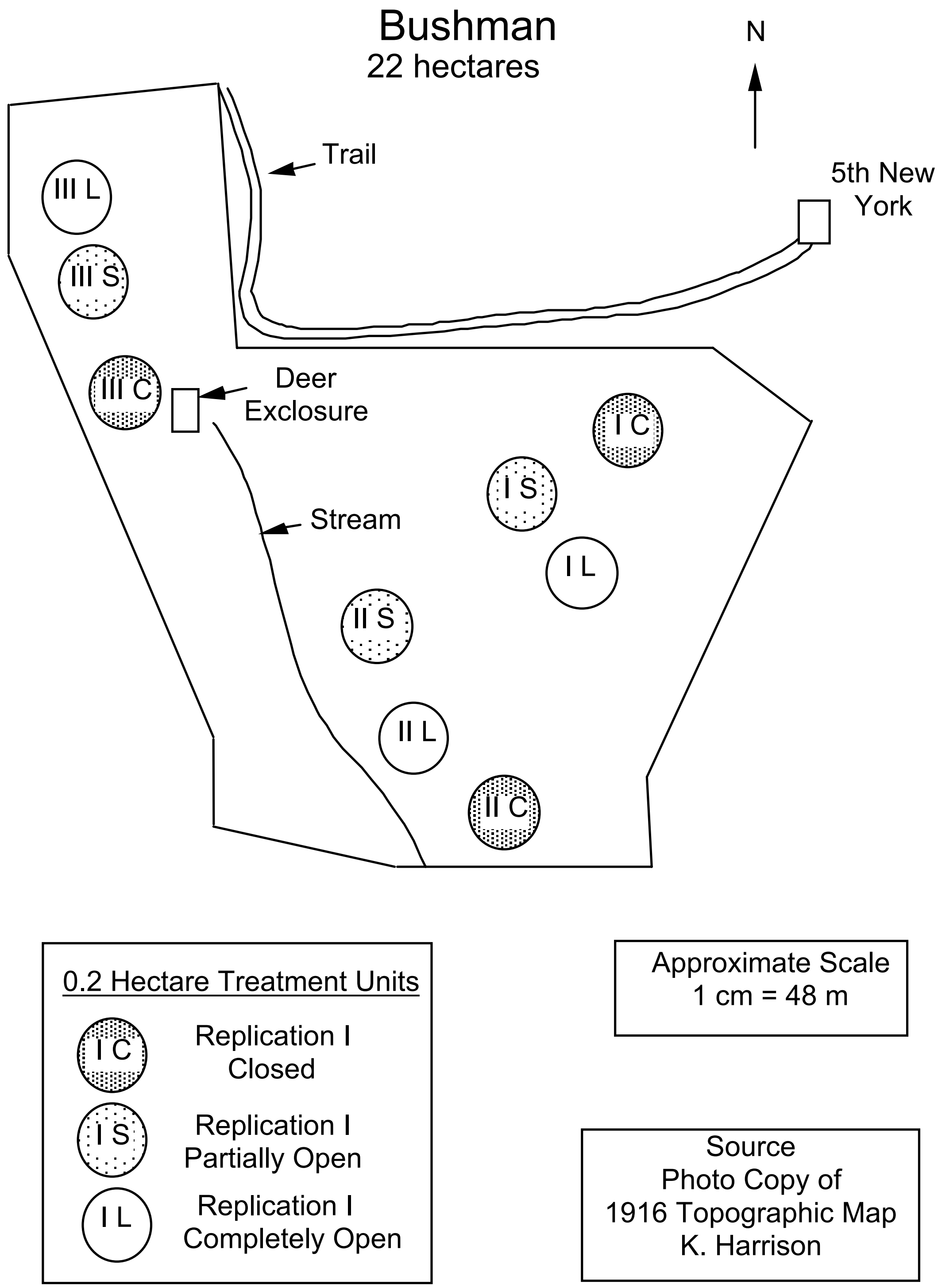
Appendix A. Common and scientific names of herbaceous (forbs and grasses), shrub, tree and vine species identified during the study and presented in this report (continued).

Violaceae	*Viola sororia* Willd. - common blue violet (F)
Vitaceae	*Parthenocissus quinquefolia* (L.) Planch. - Virginia-creeper (V)
	Vitis spp. - grape species (V)

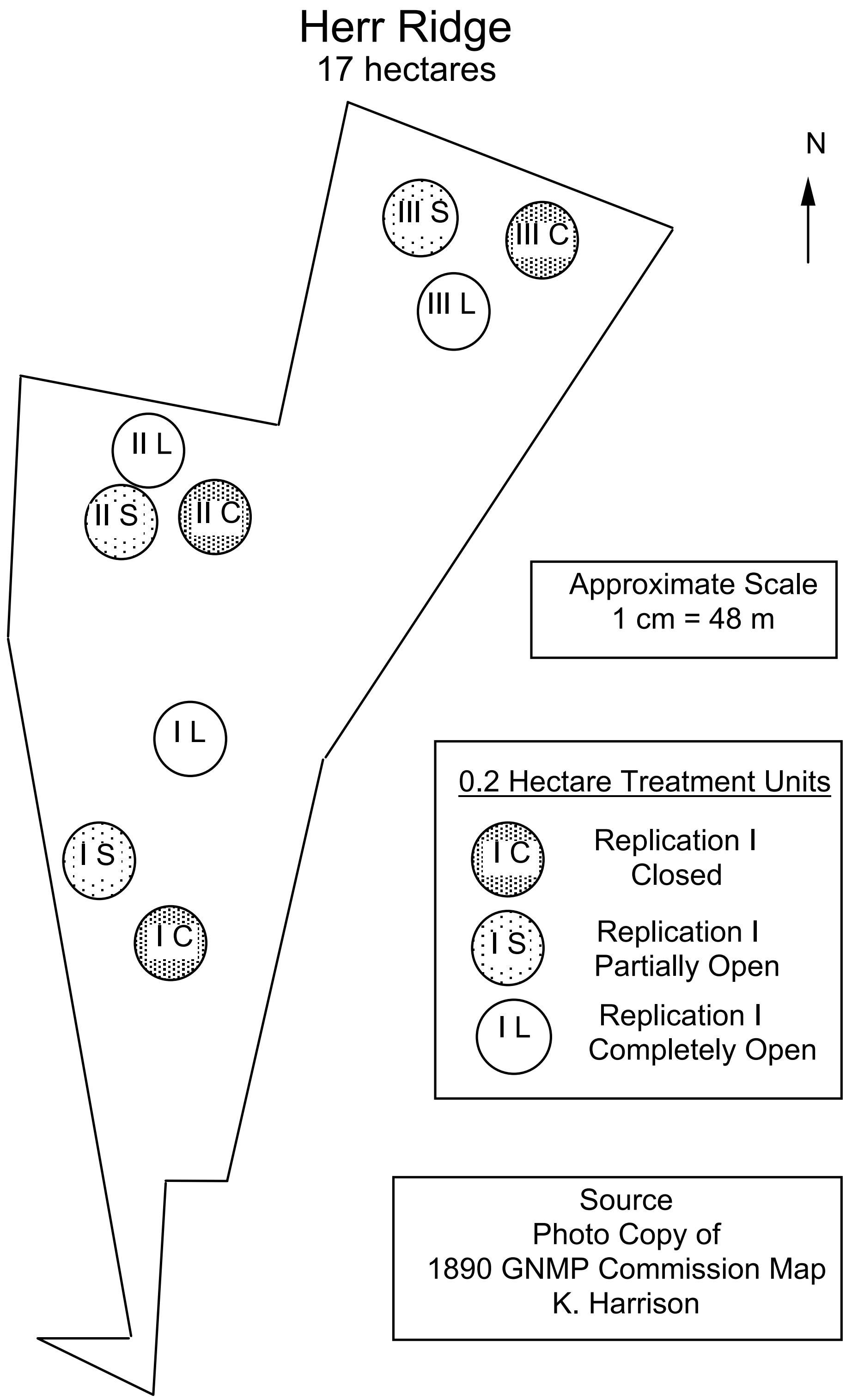
Appendix B. Diagrams of study design, maps of woodlots with locations of treatment units, and treatment unit layout and plot designs.



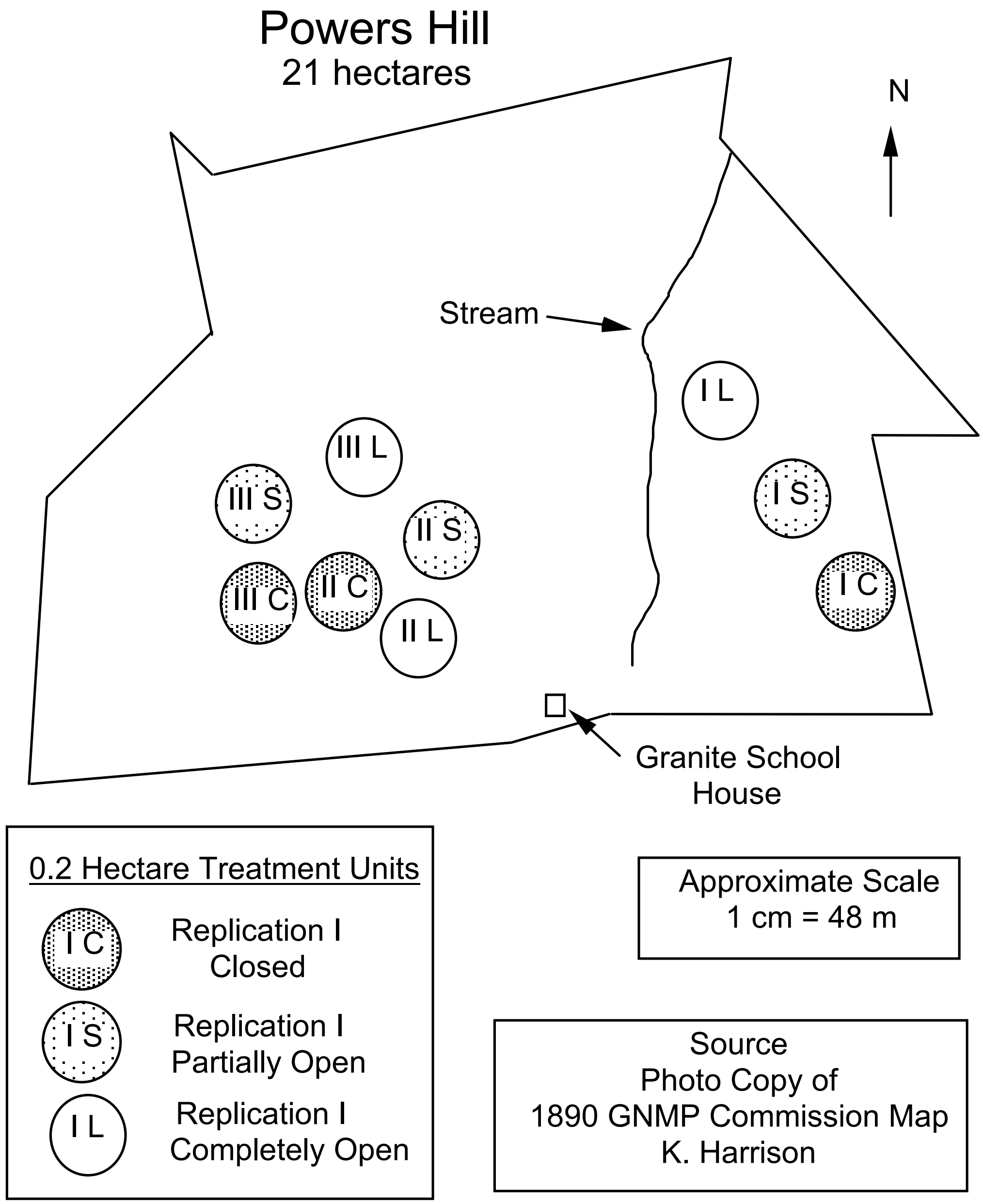
Appendix B-1. The organization of the three canopy treatments per replication and the three replications among the three woodlots.



Appendix B-2. Map of Bushman Hill woodlot indicating locations of the three replications of the three canopy treatments.



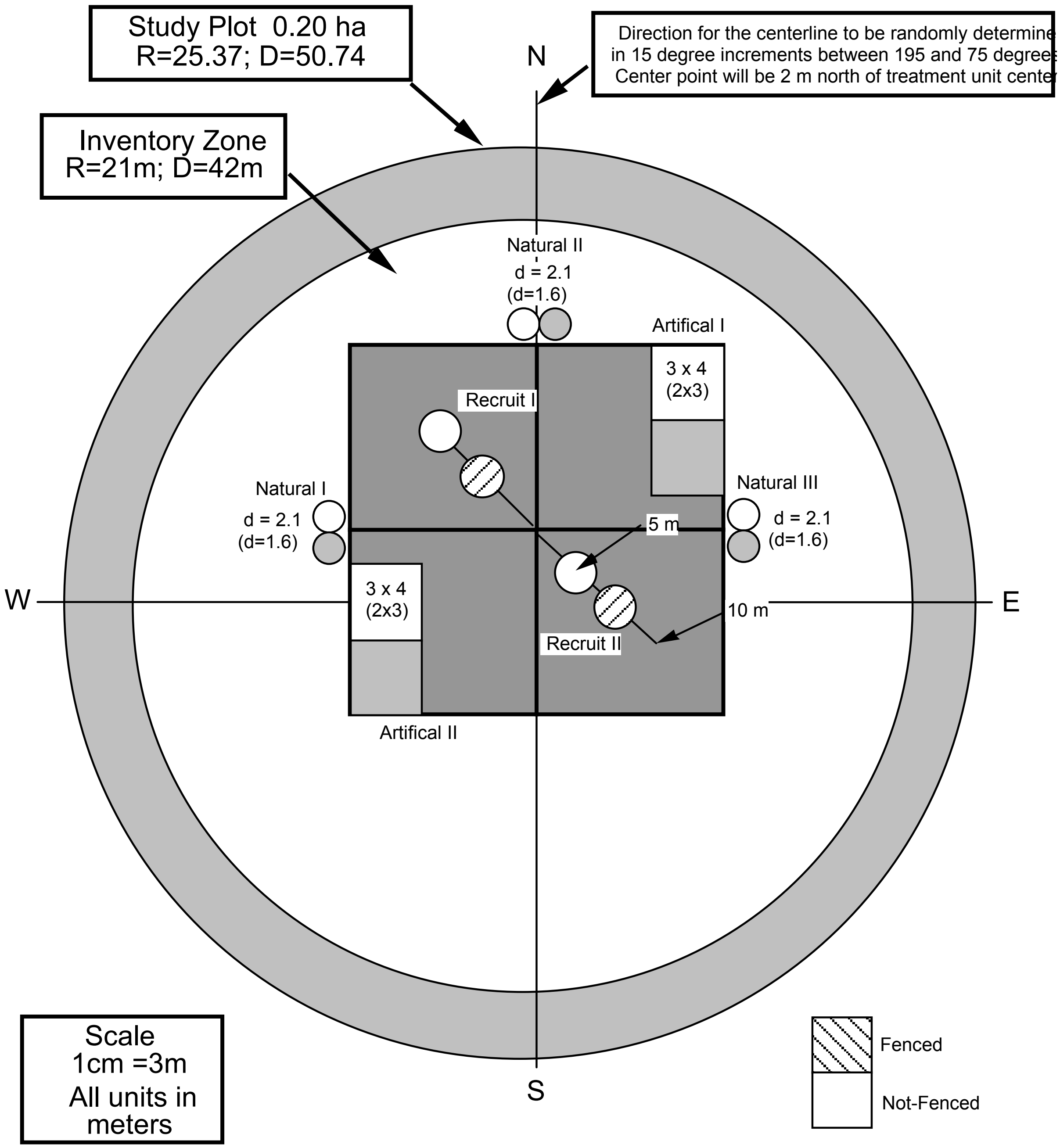
Appendix B-3. Map of Herr Ridge woodlot indicating locations of the three replications of the three canopy treatments.



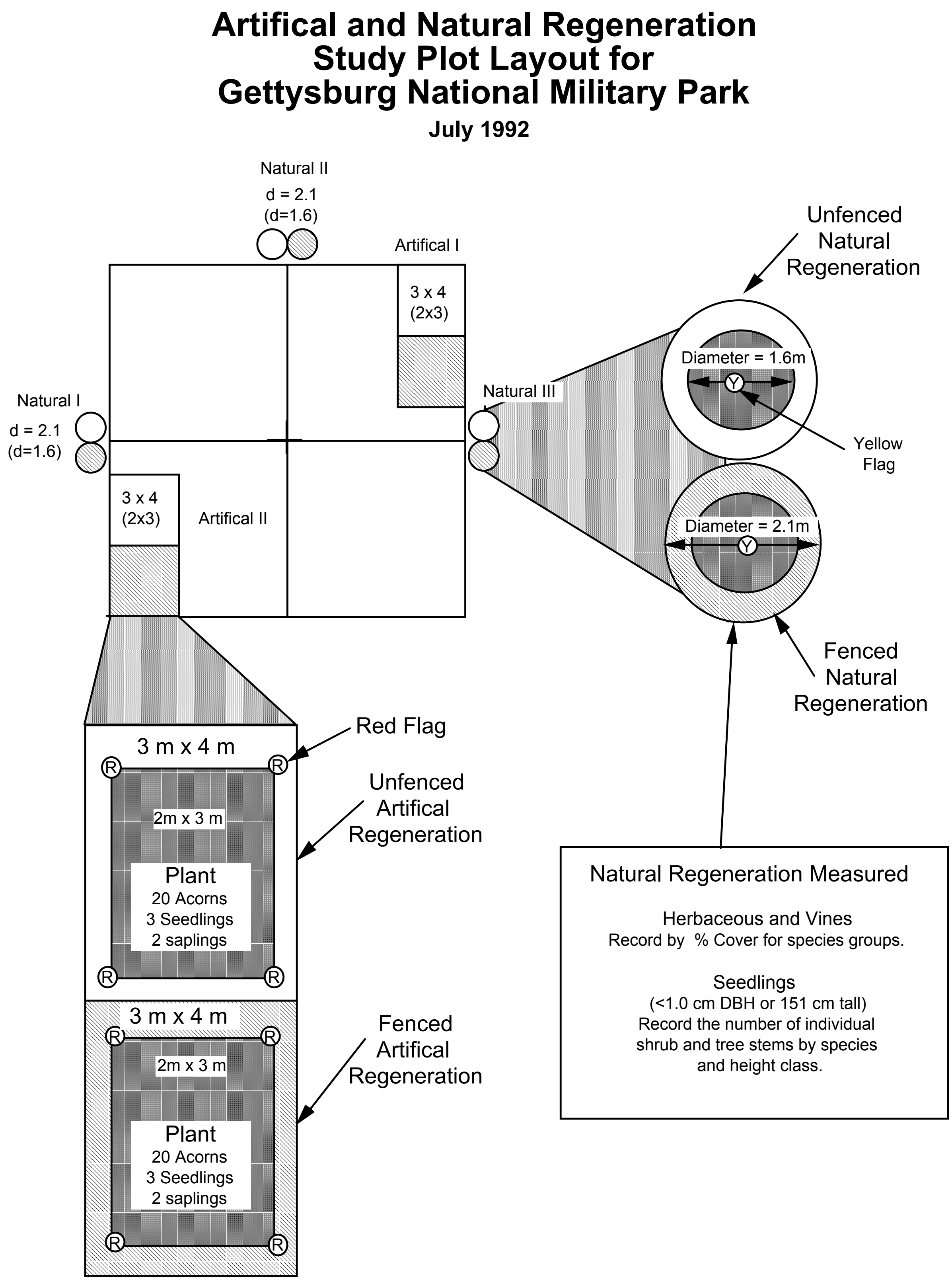
Appendix B-4. Map of Powers Hill woodlot indicating locations of the three replications of the three canopy treatments.

Overall Study Plot Layout

for
Gettysburg National Military Park
July



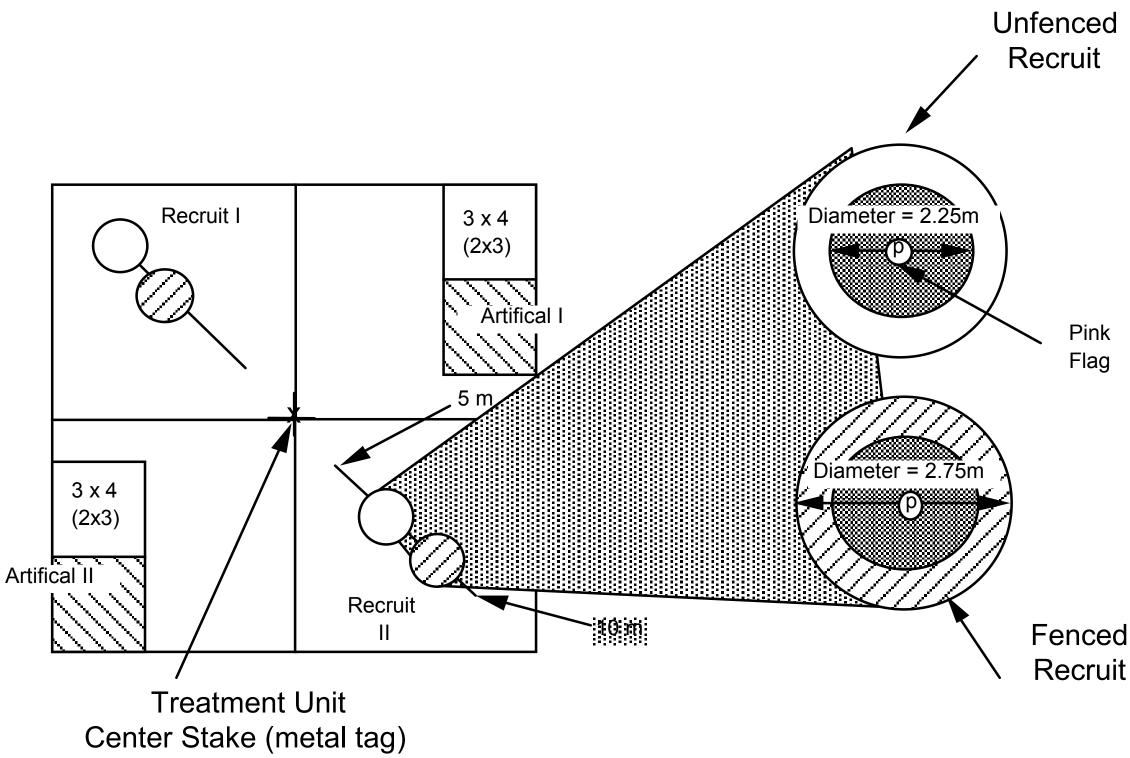
Appendix B-5. Overall individual treatment unit plot layout.



Appendix B-6. Artificial and natural regeneration plot layout.

Recruitment Study Plot Layout for Gettysburg National Military Park

April 1993



Location of Recuritment Plots

Two pairs of 4.0 2m fenced and unfenced plots. Each pair are to be located on diagonal of the 10 x 10 m sapling plots that do no contain the artifical regeneration plots.

A recruitment plot center is located a random point between 5 and 10 m from treatment unit center stake. Fence or no-fence is randomly assigned.

A second plot is located 3 m beyond the first plot. The plot pair will be labeled with a metal tag on the fenced plot stake.

Plot radius = 1.13 + 0.25 border
Plot diameter =2.25 + 0.5 border

Litter Treatments

Northern hemisphere of each plot will be assigned to either litter intact or litter removed treatment.

Litter removed is removal of recent litter prior to the start of the first (1993) and second (1994) growing seasons after overstory treatment.

Appendix B-7. Recruitment plot layout.